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Two Simulation Studies of Precision Runway Monitoring of Independent Approaches to Closely Spaced Parallel Runways

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Lincoln Laboratory

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16. Abstract

This report documents the findings of two simulation studies of air traffic controller reaction to the Precision Runway Monitor (PRM). The PRM is a new system for monitoring independent approaches to closely spaced parallel runways. It consists of a radar which has higher accuracy and a faster update interval than the current system. The PRM radar is accompanied by a high-resolution color display which provides automated visual and vocal warnings to alert controllers of impending and actual penetration of a "No Transgression Zone" between parallel runways.

The studies were conducted in order to determine the effects of key variables on controller reaction time and to determine controller opinion on system acceptability. Study I examined the use of the PRM when the runway separation was both 3,400 ft and 4,300 ft. Study II examined the use of the PRM when the runway separation was 3,000 ft.

Real-time simulated approach blunders were presented to controllers, and measurements of their reaction times were recorded and analyzed. Independent variables studied included sensor update interval, runway separation, deviation angle, deviation range, flight path condition, approach blunder type, and controller experience level. In addition, controller opinions of the PRM were surveyed.

Findings regarding the effects of each of the variables are reported. Survey results of controller opinion are reported. Recommendations for enhancing the realism of the simulation and recommendations of issues for future study are discussed.

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EXECUTIVE SUMMARY

This report documents the findings of two studies of air traffic controller reaction to the Precision Runway Monitor (PRM). The studies were conducted in order to determine the effects of key variables on controller reaction time and to determine controller opinion on the acceptability of the system.

BACKGROUND

The primary purpose of radar monitoring is to insure safe separation of aircraft arriving on the parallel approach courses. This separation is compromised if an aircraft deviates off course towards an aircraft on the adjacent approach. The PRM was designed to facilitate the monitoring process.

The PRM is a new radar monitoring system which consists of radar which has higher accuracy and a shorter update interval than the current system. The PRM radar is accompanied by a high-resolution, color display which provides automated visual and vocal warnings to alert controllers of impending and actual penetration of a "No Transgression Zone" (NTZ) between parallel runways.

STUDY METHOD

Fifty air traffic controllers participated in Study I, which examined the use of the PRM when the runway separation was both 3,400 ft and 4,300 ft. Ten air traffic controllers participated in Study II, which examined the use of the PRM when the runway separation was 3,000 ft. Both studies were conducted at Memphis International Airport.

The testing consisted of the presentation of real-time simulated approach blunders and measurement of controller reaction time in directing endangered aircraft out of the path of an aircraft deviating from the adjacent parallel approach. Controller reaction was measured in terms of Alert Response Time (ART). Measurement of ART begins when the Caution Alert is given and ends when the controller begins to speak the breakout instruction to the endangered aircraft.

Independent variables explored included: sensor update interval, runway separation, deviation angle, deviation range, flight path condition, approach blunder type, and controller experience level. In addition, controller opinions of the PRM were surveyed.

OVERALL RESULTS

Results of Study I indicated that with 3,400-ft runway separation, controller reaction time was not significantly affected by sensor update interval in the case of 1.0-s vs 2.4-s sensor update interval. However, significant delays in reaction time did occur when the update interval was 4.8 s. While controller reaction time was not significantly affected in the case of 1.0-s vs 2.4-s sensor update interval, the faster sensor update interval did demonstrate some advantages. The faster sensor update interval provided increased advanced warning that translates into a greater missed distance between aircraft. The faster sensor update interval resulted in a lower false breakout rate that translates into less arrival delays.

Deviations of 30 deg were found to result in quicker reaction times than the lesser deviations of 15 deg. Deviations occurring far from the runway threshold resulted in slower reaction times in comparison to deviations occurring near the runway threshold. No major effects were attributable to flight path condition and approach blunder type. Experienced Monitor Controllers demonstrated

slower reaction times than controllers who did not have Monitor Controller experience. Regarding the 4.8-s sensor update interval, it was found that controller reaction was significantly faster when the runway separation was 4,300 ft as compared to 3,400 ft.

Results of Study II indicated that with 3,000-ft runway separation, whether the sensor update interval was 1.0-s or 2.4-s, controller reaction time remained basically the same. The reaction times did not differ significantly from those of Study I in which the same update intervals were used but the runway separation was 3,400 ft. However, due to the closeness of the runways in the case of 3,000-ft separation, total navigational system error (TNSE) caused a number of aircraft to near or enter the NTZ. As a result, nuisance alerts occurred and the probability of false breakouts increased.

Controllers' opinions of the system indicated a high level of acceptance. The vast majority of controllers felt that the system could be used to safely conduct independent approaches to runways with 3,400-ft spacing if a 1.0-s or 2.4-s sensor update interval were used. Controllers were divided on their opinion of the safety of use of the system when runways are separated by 3,000 ft. The major concern was the effect of TNSE mentioned above.

RECOMMENDATIONS

Recommendations are made regarding ways in which to enhance the realism of the simulation, if future studies were to be conducted. The inclusion of background noise appropriate to the work-setting is recommended. Enhancements to the recorded audio are recommended.

Recommendations are made for further testing of the case of 3,000-ft runway separation. It is also recommended that the look-ahead time for the Caution Alert be further explored.

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1. INTRODUCTION

Increased air travel in recent years has resulted in a steady increase in the number and duration of flight delays. Airports have not been able to expand to keep pace with traffic growth. In an attempt to increase airport capacity, the Federal Aviation Administration (FAA) has taken a variety of measures to increase airport capacity. Measures have included revisions to air traffic control procedures, addition of landing systems, taxiways, and runways; and application of new technology.

The Precision Runway Monitor (PRM) is a prime example of the use of new technology to address the need for increased capacity. The PRM is an advanced radar monitoring system designed to increase utilization of closely-spaced, multiple, parallel runways during adverse weather conditions. The main objective of the PRM Program is to develop an improved radar and the associated procedures necessary to lower the minimum required spacing between parallel runways for independent Instrument Landing System (ILS) operations.

Two versions of the new radar and accompanying display system for the air traffic controllers were developed by the FAA through contract with MIT Lincoln Laboratory and MSI Services, Inc. Prototypes of the systems were installed at two airports. The Lincoln Laboratory prototype, the Mode S Sensor, was installed at Memphis, TN, International Airport. The MSI and Bendix Corporation prototype, the E-Scan Sensor, was installed at Raleigh-Durham, NC, International Airport.

In both prototype systems, the new monitoring equipment consists of radar and displays. The radar portion of the prototypes were not functionally equivalent. A radar having electronically scanned antenna capable of half-second update intervals was installed at Raleigh, while a Mode S-based sensor with a mechanically rotating "back-to-back" antenna capable of 2.4-s sensor update intervals was installed at Memphis.

The display portion of both prototype systems were functionally equivalent. The display presents simultaneous approaches to parallel runways on high-resolution, color, and expanded screen. As decision aids for the air traffic controllers, two-level, color-coded, visual and audible alerts were included.

A human factors approach was used in the design of the display. Potential users of the display played a key role in its development. A group of experienced air traffic controllers from Memphis and Raleigh-Durham Air Traffic Control (ATC) Towers worked as part of the design team. This group is referred to as the Core Group of Controllers. Together with hardware and software engineers and a human factors psychologist, the various elements of the display were identified and implemented. The PRM Display is briefly discussed in Section 3.1.2.1. For a detailed description of the elements included in the display the reader is referred to "User's Guide to the MIT Lincoln Laboratory Precision Runway Monitor System" [1].

1.1 EVALUATION OF SYSTEM EFFECTIVENESS

In order to evaluate the effectiveness of the PRM, a myriad of data were collected. This was done in order to address concerns inherent in making a decision regarding

(1) whether or not the current standard for runway separation of 4,300 ft can be reduced to 3,400 ft or less when the PRM is used, and

(2) whether or not a 1.0-s or 2.4-s sensor update interval is required.

The data collected at Raleigh-Durham include pilot response times gathered through live aircraft testing and simulation. They also include air traffic controller response times in using the PRM to monitor simulated, independent parallel approaches. The data collected at Memphis include pilot response times in live aircraft testing and air traffic controller response times in using the PRM to monitor simulated, independent parallel approaches. Memphis data also include measurements of total navigational system error (TNSE) [2]. Data on pilot response times were collected through simulator studies conducted by the FAA Standards Development Branch [3, 4].

Much of the data collected were used as input to a risk assessment model developed by Lincoln Laboratory [5, 6]. The model provides a means for quantifying the risk inherent in conducting independent approaches to closely-spaced parallel runways. It is a useful tool for evaluating changes in risk which result from varying the values of relevant variables.

Partial findings regarding the effectiveness of the PRM were documented in "The Precision Runway Monitor Demonstration Report" [5], published in February 1991. The report documents key results obtained from the PRM equipment demonstrations and studies at the Memphis and Raleigh-Durham airports. It includes the results of application of the risk assessment model. The report recommends a new standard for the minimum allowable runway separation for independent approaches to parallel runways. It recommends that:

> the FAA issue a national standard for runway spacing of 3,400 ft, provided the approaches can be monitored by displays equivalent to those used in the demonstration, driven by a radar accurate to within 1 milliradian with an update interval of 2.4 s or less. With this equipment, the risk of a blunder resulting in less than 500 ft of separation when two aircraft are on parallel approach in IFR conditions, is less than one in 250 million instrument approaches. This recommendation is contingent on successful deployment of a satisfactory surveillance and display system. A familiarization program to ensure that all pilots understand their responsibilities during a closely-spaced parallel approach will also be required. An off-centerline obstruction evaluation will be conducted at all airports where the PRM is to be installed.

1.2 SCOPE OF THIS REPORT

The current report documents the findings of one portion of the data collected in the data collection effort, briefly described above. The report focuses on the reactions of the air traffic controllers who participated in two PRM studies conducted at Memphis International Airport.

Study I was conducted from February 5 to August 3, 1990, and examined the effectiveness of the PRM in aiding controllers in monitoring independent approaches to parallel runways separated by 3,400 ft and 4,300 ft. As a follow-on study, Study II was conducted from November 26 to December 12, 1990, and examined independent approaches to parallel runways separated by 3,000 ft.

Controller reaction results from Memphis appeared in "The Precision Runway Monitor Demonstration Report" [5]. However, they were presented at a summary level. Report deadlines prevented, in some cases, inclusion of a portion of the controller reaction data collected in the Memphis Studies. The purpose of the current report is to provide a detailed analysis of those controller reactions and to discuss how those reactions were affected by key variables. Although a risk assessment model may tell us that an operation is "safe," the analysis of the effect of each variable tells us how reactions varied within that safety window.

1.3 ORGANIZATION OF THIS REPORT

Section 1 includes a discussion of the capacity problem which lead to the development of the PRM. It also provides background information on independent and dependent approaches and their effect on capacity. The role of the Monitor Controller, who is the user evaluating this system, is discussed.

Section 2 explains the experimental design used in collecting the controller data in both Memphis Studies. All independent and dependent variables are defined. The stimulus for eliciting the response of the controllers is also discussed, i.e., simulated approach blunders.

Section 3 details the methods and exact procedures followed, as well as the procedures for data collection. Section 4 discusses the results of Study I. Section 5 discusses the results of Study II. Section 6 gives conclusions and recommendations for future study.

1.4 BACKGROUND

1.4.1 The Capacity Problem and the Development of the PRM

Airport capacity is significantly enhanced when independent approaches to parallel runways are available. Current FAA procedures permit independent approaches in instrument meteorological conditions (IMC) when the parallel runways are spaced at least 4,300 ft apart. At airports that have parallel runways separated by less than 4,300 ft or have converging runways, arriving aircraft must be dependently sequenced, a procedure that reduces the arrival rate.

The need for greater airport capacity has led to intense interest in the use of new technologies that can support independent parallel IMC approaches to runways having spacings as little as 3,000 ft.

This interest resulted in several new FAA initiatives, including an evaluation of the applicability of sensors capable of high accuracy and rapid update. The sensors were installed at Memphis and Raleigh in order to assess the feasibility of using them for parallel runway approach monitoring.

1.4.2 Simultaneous Instrument Landing System Procedure

Section 1.4.2 through 1.4.6 are provided in order to help the reader understand current approach procedures and the potential benefits of the PRM. These sections describe how pilots navigate and how controllers direct them to land in bad weather. These techniques are first described for a single runway, and then for multiple runways at the same airport. Next, existing limitations to full runway utilization are explained, followed by a discussion of how the limitations might be avoided with the PRM.

1.4.3 Instrument-Approach Procedures

During IMC, a variety of procedures have been developed to guide appropriately equipped aircraft safely to the vicinity of the runway. The most precise procedure in common use is the Instrument Landing System (ILS). Radio-navigation signals identify a precise flight path, laterally with the localizer, and vertically with the glide slope. The signals are displayed to the flight crew on an instrument that indicates the location of the flight path relative to current aircraft position.

At busy airports, air traffic controllers use radar to direct the aircraft to intercept the localizer 5 to 15 nautical miles (nmi) from the runway threshold. Aircraft reach this intercept one at a time, separated by at least 3 nmi from the aircraft ahead. The aircraft then follow the localizer signal at constant altitude, and begin descending when the glide slope is intercepted. When an aircraft reaches the missed approach point (MAP), typically 0.5 nmi from and 200 ft above the runway threshold, the flight crew must be able to see the runway environment and complete the landing visually. If they are unable to do so, they must reject the landing and follow a missed approach procedure.

1.4.4 Parallel Runway Simultaneous ILS Approaches

The procedures for airports with multiple parallel runways are similar, with added safeguards to ensure that an aircraft approaching one runway is safely separated from those approaching the adjacent parallel runway. The procedures are discussed in [7], and an example of such procedures is diagrammed in Figure 1-1. Aircraft are directed to the two final approach courses at different altitudes separated by at least 1,000 ft. The separation is necessary because the normally maintained 3-nmi separation is lost as the aircraft fly toward their respective localizers. This 1,000-ft vertical separation is maintained until the controller sees that each aircraft is stabilized on its parallel localizer course. Then, the aircraft are allowed to descend on their respective glide slopes, flying towards the airport separated by the distance between the runway centerlines.

Because this separation is much less than the 3 nmi normally maintained, the two aircraft are monitored on radar starting when the 1,000-ft altitude buffer is lost as the higher aircraft starts down the glide slope. Two controllers, called Monitor Controllers, observe the parallel approaches and ensure that if an aircraft blunders from the normal operating zone (NOZ) into a 2,000-ft NTZ, as

shown in Figure 1-1, any endangered aircraft on the other approach are turned away in time to prevent a collision. This maneuver on the part of the endangered aircraft is termed a "breakout," because the aircraft is directed out of the approach stream to avoid the blundering aircraft. Two controllers are necessary so that one can attempt to turn the blundering (deviating) aircraft back to its localizer while the other directs the breakout of the endangered aircraft. Typically, two separate radio frequencies are used, one for each approach.

The 2,000-ft NTZ, flanked by two equal NOZs, is a procedural artifice which provides strong guidance to the Monitor Controller. Aircraft are allowed to operate on or near the approach course within the limits of the NOZ. If an aircraft strays into the NTZ, it is deemed to create a hazard for an aircraft on the adjacent course. The NTZ width was established to provide time to resolve the situation by redirecting either or both aircraft before a collision occurs. The 2,000-ft NTZ width has an uncertain origin, but pilots and controllers are confident that it is appropriate, based on many years of application at the wider runway spacings.

The smaller the separation between the runway centerlines, the shorter the time that is available to correct a blunder once it begins. Parallel approaches to runways spaced less than 4,300 ft apart are restricted in IMC, in part because the radar and display systems currently available to the controller are sufficiently imprecise that the blunder cannot be detected and corrected before the aircraft are dangerously close. For these narrower runway separations, a dependent or staggered approach procedure is used to eliminate the risk.

In the dependent procedure, controllers position aircraft so that there is always at least 2 nmi separating one aircraft from another on the adjacent runway. This ensures that if an aircraft blunders toward the adjacent approach, the aircraft will pass through a gap and will not encounter another aircraft. Figure 1-2 diagrams the two situations: (1) simultaneous independent parallel approaches, when aircraft on one runway are spaced independently of those on the other runway (for runway spacings of 4,300 ft or greater), and (2) dependent parallel approaches, when aircraft spacing is dependent on the position of aircraft on the adjacent runway (for spacings less than 4,300 ft). The possibility of wake turbulence restricts dependent parallel approaches to spacings of 2,500 ft or greater.

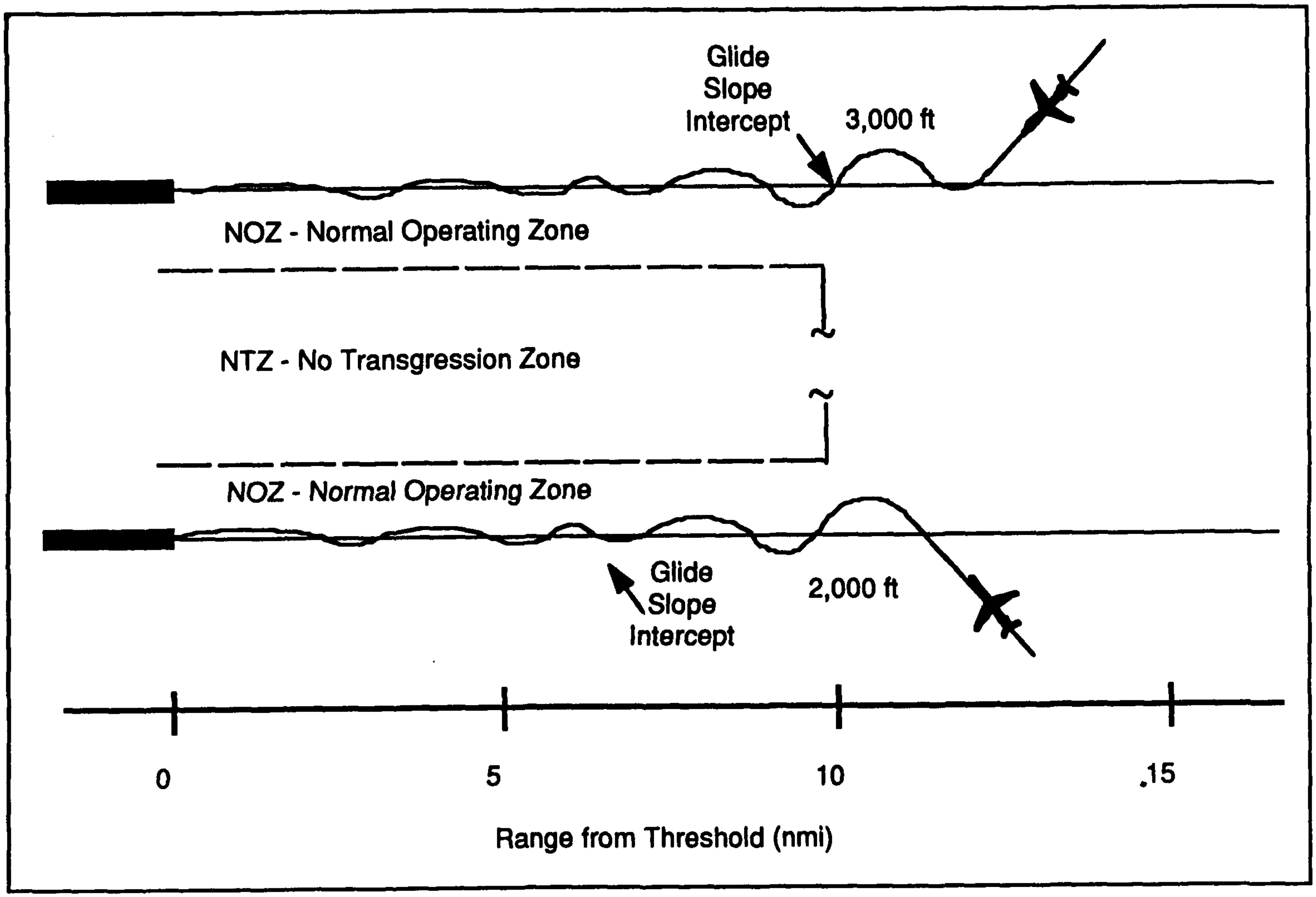

Figure 1-1. Parallel runway approach zones.

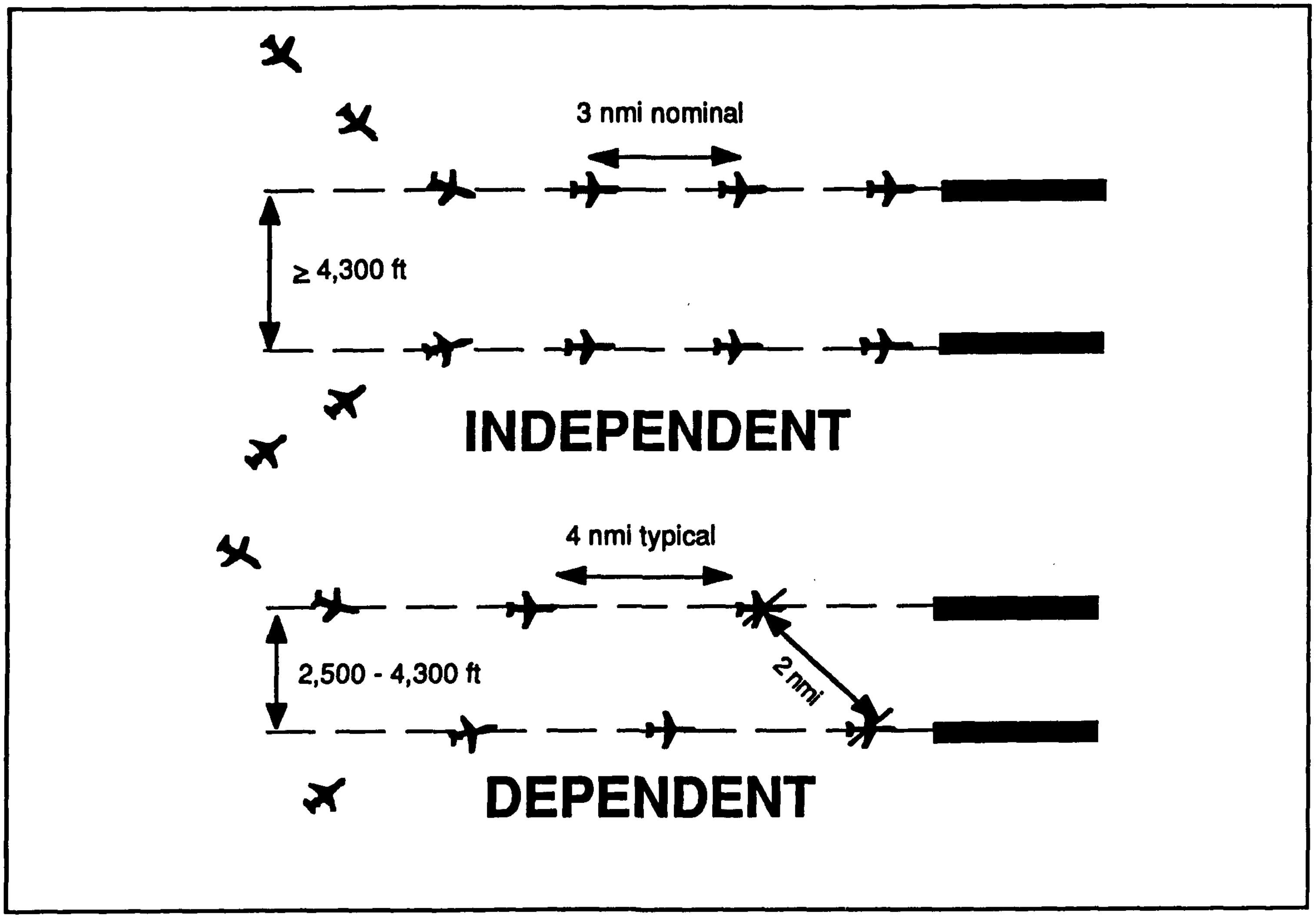

Figure 1-2. Independent and dependent parallel approaches.

1.4.5 Arrival Rate Penalties for Dependent Approaches

For independent approaches to parallel runways, the arrival rate is about twice the single runway rate, since the approaches to each runway are independent and managed by different controllers. But the arrival rate at airports using dependent parallel approaches is significantly less. The required 2-nmi diagonal separation leaves just under a 4-nmi spacing, at minimum, between aircraft on the same runway. Independent approaches leave a 3-nmi or 2.5-nmi minimum. The different spacings yield a landing rate that is about 33% higher for the independent case. In practice, however, the coordination required to exactly produce the 2-nmi diagonal spacing is much more complex, particularly as aircraft typically arrive from many different directions at a variety of speeds. To insure that the minimum is never violated, most controllers end up with a spacing somewhat greater than the minimum, a reality which penalizes the dependent case even further.

Parallel runway acceptance rates are thus significantly greater when independent approaches are available. Independence is possible at 700-ft runway spacings during visual meteorological conditions (VMC), but only at 4,300 ft or greater during IMC. Numerous busy airports face serious and costly arrival delays during IMC for this reason. Other airports with single runways are considering an additional parallel runway but are dissuaded from constructing it because land acquisition for a 4,300-ft separation is either impossible or extremely expensive.

The motivation for the PRM is clear: If improved radar surveillance and ATC displays would lead to earlier blunder warning to the controller, independent approaches could be authorized at spacings less than 4,300 ft. Arrival capacity could be increased immediately at some airports, and construction at other airports would yield greater benefits. Figure 1-3 shows parallel runway spacings at some busy airports that could benefit from a PRM.

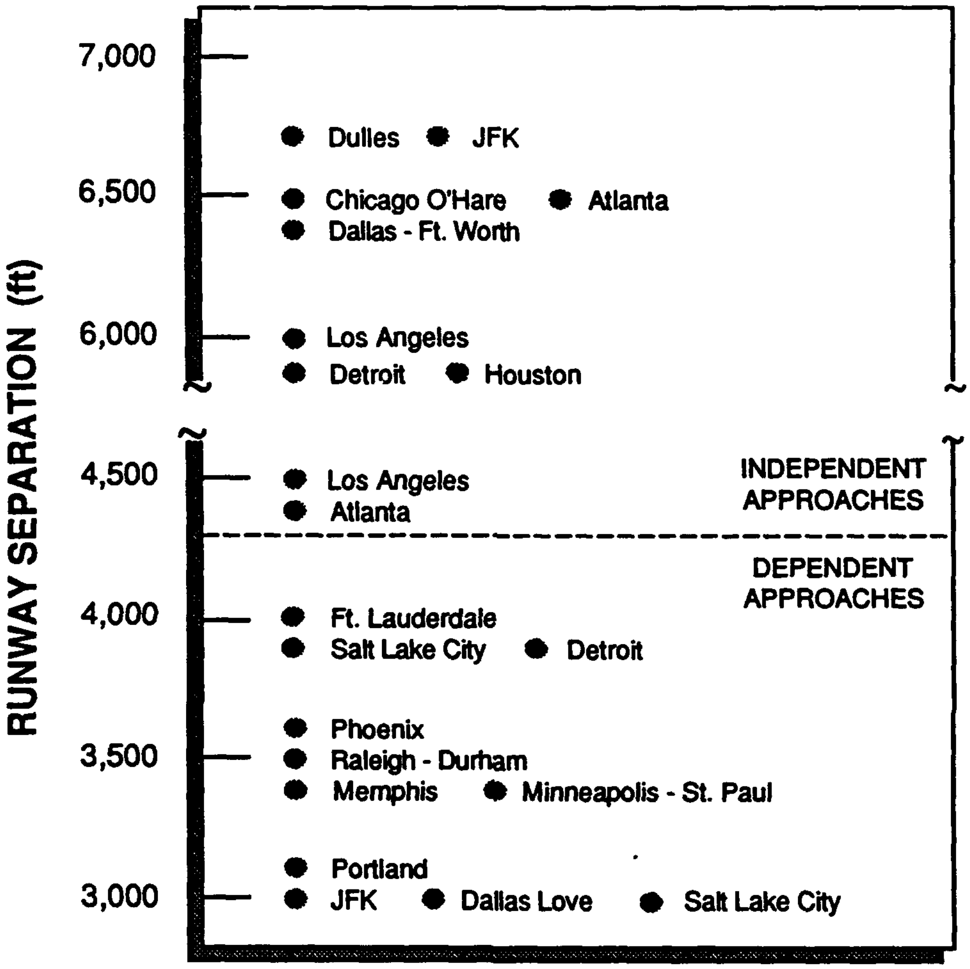

Figure 1-3. Parallel runway spacings. (Airports with multiple runway pairings, such as Los Angeles, appear twice.)

2. EXPERIMENTAL DESIGN

Two controlled experimental studies were conducted in which simulation of approach blunders to closely-spaced parallel runways were used to measure controllers' responses to these emergency situations. Study I examined a runway separation of 3,400 ft. As a result of that study, a second study, Study II, was conducted which examined a runway separation of 3,000 ft.

Both studies involved the measurement of controller reaction time in breaking out endangered aircraft when an approach blunder was committed by an aircraft on the adjacent parallel approach. Through assessment of their responses, the effectiveness of the PRM system, when used with runway separation which is less than the current standard, could be evaluated. Opinion surveys were used in order to obtain user opinion on the safety of the system. Comments on user preferences were obtained regarding information content and presentation within the display.

In order to evaluate the effectiveness of the PRM and the effects of key variables on controller reaction time, controllers were presented with simulations of various types of approach blunders, which were systematically varied in each presentation. This allowed the exploration of the effects of each of the variables on the response times of the controllers. The major design of the studies was a within-subject, paired-sample design. This means that each controller was exposed to one variable condition at a time during a sequence of approach blunder presentations. The controller's reaction time during one variable condition could then be compared to his or her own reaction time during another variable condition.

In studying the effects of the variable "controller experience level," a between-subject, independent-sample design was used. This design was used since measurements were taken of two groups of controllers, i.e., controllers with and controllers without Monitor Controller experience. In studying the effects of "runway separation," a between-subject independent sample design was used. This design was used since two different groups of controllers reacted to the condition of 4.8-s sensor update interval, i.e., one group was shown simulations depicting 3,400-ft runway separation and the other group was shown 4,300-ft runway separation.

Simulation was selected for use as the means of testing, since it provides several benefits. Approach blunders are a rare event in actual air traffic operations. Through simulation, the controllers were exposed to the occurrence of approach blunders, and, therefore, their reactions could be observed. The use of simulation allowed for control of the experimental variables which were manipulated. It enabled the experimenter to ensure that every pair of controllers who participated in the experiment witnessed and had the opportunity to react to exactly the same stimulus as all other controllers who participated in the experiment.

2.1 STUDY I

2.1.1 Independent Variables – Study 1

In each of the monitoring sessions, there were a number of independent variables which it was believed might affect the controller's responses. The variables were:

(a) Sensor update interval. As the primary variable, this would differentiate between the PRM alternatives, and combined with accuracy, differentiate the PRM from older

sensors. In the simulations, sensor update intervals of 1.0 s, 2.4 s, and 4.8 s were tested. A 4.8-s interval was of interest because monopulse sensors, planned to replace existing beacon sensors around the world, will rotate with this period and provide the same 1-milliradian accuracy as the PRM. Although the back-to-back radar at Memphis was limited to a 2.4-s interval, the simulation did not require the radar itself, and the displays were not interval-limited.

(b) Deviation angle. Approach blunders were staged using the worst case scenario, where an aircraft rolls smoothly into a standard rate turn and holds the bank until a 30-deg heading change (deviation) toward the adjacent approach course is achieved. Approach blunders having a 15-deg heading change were also staged to measure the system's performance for less severe approach blunders.

(c) Range of the approach blunder from runway threshold. Approach blunders were staged both outside and inside the outer marker and after the missed approach point. The difference is important because of the contribution of total navigational system error (TNSE) to the blunder starting conditions and the relative stability of the aircraft at the various spacings. TNSE consists of the error attributed to aircraft flight characteristics, pilot flying technique, and the ILS (Instrument Landing System).

(d) Flight Path Conditions. Simulation arrival periods modeled both calm conditions and more turbulent conditions. Turbulent conditions increase the amount of TNSE during the ILS approach. It was suspected that controllers might become more tolerant of deviations due to turbulence and might delay their responses. This might occur because the beginning of an approach blunder could appear to be a result of the increased TNSE. In Study I, TNSE consisted of a sinusoidal oscillation off the scripted flight path that dampened down to zero amplitude at landing. The amplitude of the oscillations at a range of 15 nmi was one value for "calm wind conditions" and a larger value for "turbulent conditions." This TNSE, based on preliminary radar observation, was reviewed by the Memphis Core Group and determined to be representative.

(e) Types of Approach Blunders. Various types of approach blunders were studied. Types consisted of "Single," "Fast/Slow," "Distraction," and "Simultaneous Missed Approach" Blunders.

1) In a "Single" blunder, one aircraft penetrated the NTZ and endangered the aircraft on the adjacent approach path. Blunders were staged with both aircraft operating at speeds typical of transport jets.

2) A "Fast/Slow" blunder involved one aircraft that was fast (an air carrier traveling at 150 knots) and one aircraft that was slow (a general aviation aircraft traveling at 90 knots). The fast aircraft penetrated the NTZ and blundered toward the slow aircraft on the adjacent approach path.

3) A "Distraction" blunder was a "Single" blunder preceded by a distraction. One aircraft had an erratic flight path (one that is not due to turbulent conditions but presumably due to the performance of the pilot or aircraft). Then the aircraft on the adjacent approach path deviated and penetrated the NTZ. It was believed that

a distraction might cause increased workload and a resulting delay in controller response time.

4) A "Simultaneous Missed Approach" blunder involved two aircraft, each on adjacent approach paths. Each aircraft performed a missed approach at the same time and then blundered toward each other and the NTZ.

(f) Controller Experience Level. Approximately half of the controllers who participated in the study were experienced Monitor Controllers, and half were controllers who had no previous experience as Monitor Controllers.

(g) Runway separation. A major finding of the report was expected to center on the applicability of the PRM at runway spacings near Memphis' 3,400-ft runway. However, in order to examine the effect at different spacings, a 4,300-ft simulation was conducted near the latter half of Study I to replace the 3,400-ft, 4.8-s sensor update interval scenarios on which sufficient data had already been collected. Therefore, as of Week 13 (of 25 weeks of testing), runway separation became an independent variable.

Since the testing needed to be done within the time constraint of one week per subject pair, all combinations of the variables were not tested in each type of approach blunder and each sensor update interval. Therefore, the PRM Working Group chose to test only approach blunders of greatest interest. The PRM Working Group consisted of representatives from: the PRM Program Office, Flight Standards, Air Traffic Control, FAA Technical Center, Aviation National Standards Office, Memphis and Raleigh-Durham Air Traffic Control Tower, MIT Lincoln Laboratory, and MSI. The combinations of variables selected for testing are presented in Tables 2-1 through 2-3. Table 2-1 lists the approach blunders presented at 1.0-s sensor update interval, 3,400-ft runway separation. Table 2-2 lists the approach blunders presented at 2.4-s sensor update interval, 3,400-ft runway separation. The 1.0-s and 2.4-s, 3,400-ft runway separation approach blunders were presented to all 50 controllers for the entire 25 weeks of testing. Table 2-3 lists the approach blunders presented at 4.8-s sensor update interval, 3,400-ft runway separation (Weeks 1-12) or 4,300-ft runway separation (Weeks 13-25).

TABLE 2-1

Approach Blunders at 1.0-s Sensor Update Interval
3,400-ft Runway Separation - Weeks 1-25
Total = 13 Approach Blunders

Type:	Single								Fast/Slow					Distraction						Simult. Missed Approach	
Angle: (deg.)	15				30				15				*	15			30			15	*
Range: (nmi)	2-4		8-10		2-4		8-10		2-4		8-10		*	*	8-10		*	8-10		0.5	*
Flight Path:	c	t	c	t	c	t	c	t	c	*	c	*	*	*	c	*	*	c	*	c	*
Blunder #:	1	2	3	4	5	6	7	8	9	*	10	*	*	*	11	*	*	12	*	13	*

TABLE 2-2

Approach Blunders at 2.4-s Sensor Update Interval
3,400-ft Runway Separation - Weeks 1-25
Total = 13 Approach Blunders

Type:	Single								Fast/Slow					Distraction						Simult. Missed Approach	
Angle: (deg.)	15				30				15				*	15			30			15	*
Range: (nmi)	2-4		8-10		2-4		8-10		2-4		8-10		*	*	8-10		*	8-10		0.5	*
Flight Path:	c	t	c	t	c	t	c	t	c	*	c	*	*	*	c	*	*	c	*	c	*
Blunder #:	1	2	3	4	5	6	7	8	9	*	10	*	*	*	11	*	*	12	*	13	*

TABLE 2-3

Approach Blunders at 4.8-s Sensor Update Interval
3,400-ft Runway Separation - Weeks 1-12
4,300-ft Runway Separation - Weeks 13-25
Total = 11 Approach Blunders

Type:	Single								Fast/Slow					Distraction						Simult. Missed Approach	
Angle: (deg.)	15				30				15				*	15			30			15	*
Range: (nmi)	2-4		8-10		2-4		8-10		2-4		8-10		*	*	8-10		*	8-10		0.5	*
Flight Path:	c	t	*	*	c	t	c	t	c	*	c	*	*	*	c	*	*	c	*	c	*
Blunder #:	1	2	*	*	3	4	5	6	7	*	8	*	*	*	9	*	*	10	*	11	*

Note:
c = calm
t = turbulent
* = not tested

From review of Tables 2-1 through 2-3, it is seen that there was a total of 37 approach blunders to which each subject had the opportunity to respond during his or her week of testing.

2.1.2 Research Questions – Study I

In studying the above independent variables the following research questions were asked:

1) How does sensor update interval affect reaction time? This will give us information needed to decide whether a 1.0-s or 2.4-s sensor update interval is required for system effectiveness at 3,400-ft runway separation.

2) When the runway separation is 3,400 ft, are there differences in reaction time attributable to:

   a. the angle of the deviation of the approach blunder,

   b. the range (nmi from the runway threshold) of aircraft at time of blunder,

   c. the flight path condition during the approach blunder,

   d. the type of approach blunder; for example, one involving one aircraft at a fast speed deviating toward another aircraft at a slow speed, and

   e. controller experience level?

3) Are there differences in reaction time attributable to runway separation in feet from centerline to centerline? The specific case tested was the presentation of approach blunders at the 4.8-s sensor update interval with 3,400-ft vs 4,300-ft runway separation.

4) When the runway separation is 4,300 ft and the sensor update interval is 4.8 s, are there differences in reaction time attributable to:

   a. deviation angle,

   b. range,

   c. flight path condition, and

   d. type of approach blunder?

5) Will controllers accept the PRM system as a means of safely conducting independent parallel approaches during instrument flight rules (IFR) conditions to parallel runways spaced 3,400 ft apart?

2.1.3 Experimental Control Procedures – Study I

In order to obtain reliable and valid data to answer the research questions asked, it was necessary to collect these data in a systematic and controlled manner. Therefore, various experimental controls were used and are described in this section.

The approach blunders occurred within the context of an "arrival push." Arrival pushes are periods of peak arrivals, i.e., a high rate of arrivals. The Core Group of Controllers at Memphis Airport served as advisors to insure the authenticity of the simulation. According to the Core Group,

arrival pushes usually last for a maximum of one hour and fifteen minutes. Therefore, for the purpose of realism, the simulated arrival pushes did not exceed this time limit.

During the arrival push, each approach blunder was presented within a 15-minute period. Approach blunders occurred at various times within the 15-minute period so that the controller was not able to predict when they would occur. The first approach blunder began at a randomly selected time and was at least 5 minutes into the simulation. This was necessary, since when the simulation starts, there are just a few aircraft beginning the arrival push and it takes about 5 minutes for traffic to build up to a point in which a blunder can be inserted into the traffic.

Figure 2-1 shows an example of the timing of approach blunders in a simulated arrival push. Each dash (-) represents a minute in the 15-minute interval and the occurrence of an approach blunder is represented by an "x." A 75-minute arrival push is depicted, i.e., beginning at 0900 hours and ending at 1015 hours.

0900------x-------0915------x------0930----------x--0945-x-----------1000--------x-----1015

Figure 2-1. Simulated arrival push.

The time of occurrence for each approach blunder was determined through use of a random number list. The number of approach blunders per monitoring session were five (75-minute session), four (60-minute session), or three (45-minute session). It was not possible to have the same number of approach blunders in each arrival push since arrival pushes needed to be grouped by sensor update interval and flight path conditions. That is, all approach blunders in one arrival push were the same sensor update interval and flight path. This is done for continuity for the controllers. It would be quite disturbing to the controller to keep having momentary changes in sensor update interval and flight path conditions; and this would not represent reality.

Approximately half of the simulated arrival pushes depicted approaches to the north and half were to the south. This enables differentiation of effects that could be attributed to direction of aircraft approach. This is also typical of Memphis approaches and runway assignments. Half of the simulated approach blunders occurred on the right runway and half occurred on the left runway.

Since the approach blunders were seen by a pair of controllers, that meant that one controller in the pair had an opportunity to instruct the endangered aircraft, i.e., giving one reaction time to that approach blunder. In order to get the reaction time of both controllers, the complete set of approach blunders were presented a second time. Before beginning the second presentation, the controllers were told to change seats so that the controller monitoring the right runway would now be monitoring the left runway and vice versa.

The second presentation was different from the first in several ways so that the controllers were not aware that the same approach blunders were being presented a second time. In addition to the controllers changing seats, and, therefore, perspective, the flight identification numbers for aircraft were changed in the second presentation of the approach blunders so that the controller would not remember who blundered before and, therefore, predict an approach blunder. In their briefing prior

to the experiment, they were told that some of the scenarios may look alike but were all unique and, therefore, must be attended to carefully. Since the flight identification numbers were changed in the second set of arrival pushes, the audio was also changed to correspond to the new flight identifications (IDs).

In the first presentation, there were nine arrival pushes identified as Arrival Push 1A through 9A. The second presentation included the nine arrival pushes with the appropriate changes, as described previously. These were identified as Arrival Push 1B through 9B. Appendix A lists the arrival pushes and approach blunders shown during the first twelve weeks of testing. Appendix B lists the arrival pushes and approach blunders shown during Weeks 13 through 25 of testing.

In order to control for effects which might be attributed to order of presentation, the nine arrival pushes were presented in a counterbalanced order. If all nine arrival pushes were presented to all subjects in the same order, for example, 1, 2, 3, 4, 5, 6, 7, 8, 9, then it could be said that subjects would do better during arrival push 9 than during arrival push 1. That is, by the later arrival pushes, 5 through 9, the subject had more practice; learning had occurred; performance had improved. Therefore, controller pairs were presented with the arrival pushes in a counterbalanced order. The design has isolated order as an experimental variable. If subject performance improved during the later presentations, differences should average out across all subjects. Appendix C shows the counterbalanced order of arrival push presentations.

Since half of the approach blunders occurred on the right runway and half occurred on the left runway, a random number list was used to determine which approach blunders would occur on which runway and in which order of presentation.

Approximately three speed adjustments per arrival push are said to be typical, according to information from the Memphis Core Group of Controllers. Therefore, within the simulation, three aircraft per arrival push flew at a speed which we anticipated would cause the controller to issue an adjustment. The number of aircraft which needed a speed adjustment was controlled in an effort to keep the workload at approximately the same level for all controllers. In the simulation, the Monitor Controllers gave speed adjustments to our experimental pseudopilots, and the pseudopilots acknowledged the instruction and made the adjustments. The role of the pseudopilot is explained in the Section 3.1.2.2.1, Experimental Control Room.

2.2 STUDY II

After a preliminary analysis of the results of Study I, the PRM Working Group requested testing to look at the effect of a number of variables during simulation of monitoring runways with 3,000-ft separation. Based on the results of Study I, not all of the variables selected for study in Study I were included in Study II.

Consideration of the 4.8-s sensor update interval was excluded from Study II. The 4.8-s sensor update interval was considered to be too slow an update, considering the lessened separation between runways. It was determined that all approach blunders would occur during calm rather than both calm and turbulent flight path conditions. It was also determined that this would be a small sample study and, therefore, would involve the participation of ten subjects who were experienced Monitor Controllers. Consequently, this study did not include an examination of controller reaction

time differences attributable to controller experience level, i.e., novice vs experienced Monitor Controllers.

Changes in the visual presentations of the simulations included: (1) The airport map changed to depict runway separation of 3,000 ft rather than the 3,400 ft depicted in Study I, and (2) TNSE was increased.

TNSE was not changed as a result of Study I findings, but as a result of live aircraft data collected at Memphis. Once the live aircraft approaches recorded at Memphis were analyzed, the information was used to design an improved TNSE model for Study II. For a detailed analysis of the live aircraft data, the reader is referred to [2]. Figure 2-2 is excerpted from that report. The figure is based on the actual final approach data collected at Memphis where dependent approaches were conducted to parallel runways separated by 3,400 ft. Approximately 1,000 approaches of large and heavy aircraft were included in the database. The data were filtered for stabilized flight starting before 9.4 nmi and were collected during MVFR (Marginal Visual Flight Rules). Based on these data, extrapolations were made to estimate the percentage of aircraft that would penetrate the NTZ if independent parallel approaches were conducted to runways separated by 3,000 ft and 4,300 ft.

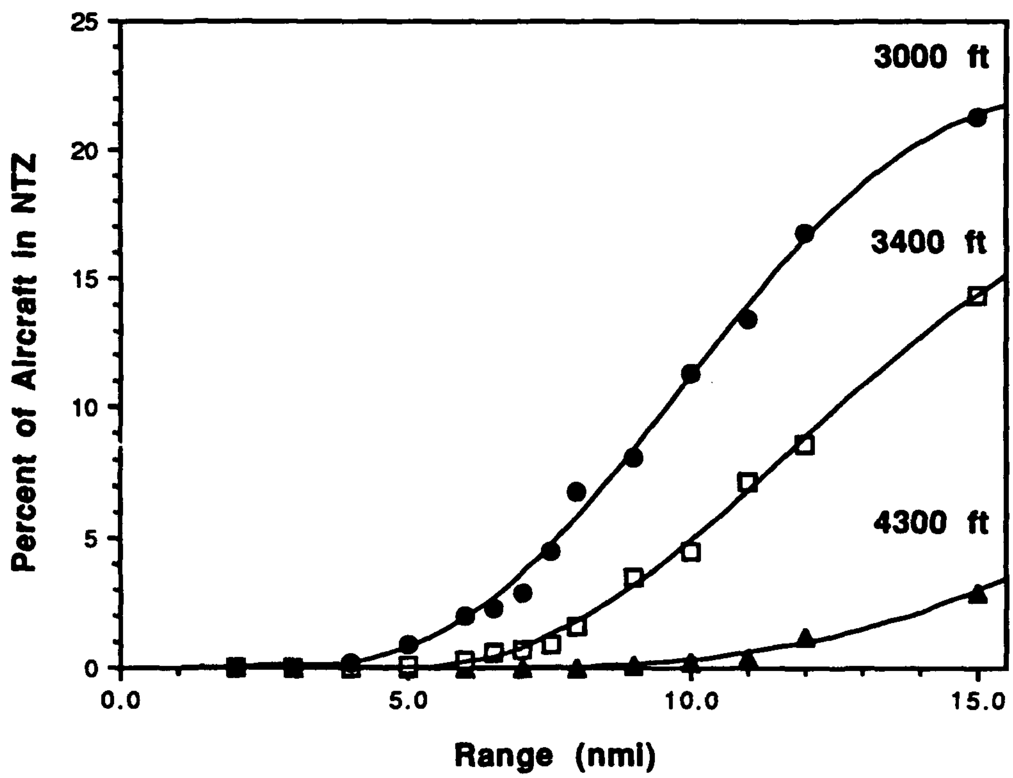

Figure 2-2. NTZ Penetrations Based on Memphis MVFR Approach Data.

Overall statistics about the average paths of aircraft and the amplitudes of their oscillations were used to create TNSE that was statistically similar to what was observed at Memphis.

The simulated final approaches were offset from the localizer beam by an angle (measured at the runway threshold) selected from a normal distribution, and the aircraft oscillated around these average flight paths starting with an amplitude also selected from a normal distribution. The new TNSE algorithm generated more Caution and Warning Alerts which were the result of the increased TNSE and were not associated with simulated approach blunders.

2.2.1 Independent Variables – Study II

(a) Sensor update interval. Two sensor update intervals, 1.0 s and 2.4 s, were explored in Study II.

(b) Runway separation. All scenarios in Study II depicted a runway separation of 3,000 ft.

(c) Deviation angle. As in Study I, the deviation angles studied were 15 deg and 30 deg.

(d) Range of the approach blunder from runway threshold. As in Study I, the approach blunder ranges staged both outside and inside the outer marker and after the missed approach point.

(e) Type of Blunder: "Single Type" and "Fast/Slow Type" blunders were studied. As a result of Study I findings, "Distraction Type" and "Simultaneous Missed Approach Blunder" were not studied. (See Section 4.1.6 for details.) For Study II, "Distraction Type" approach blunders were altered to be "Single Type" approach blunders without distractions.

2.2.2 Research Questions – Study II

In studying the above independent variables the following research questions were asked regarding 1.0-s and 2.4-s sensor update interval:

1. How does sensor update interval affect reaction time?
2. Are there differences in reaction time attributable to runway separation, specifically, 3,000 ft vs 3,400 ft.?
3. When the runway separation is 3,000 ft, are there differences in reaction time attributable to:
   a. the angle of the deviation of the approach blunder,
   b. the range (nmi from the runway threshold) of aircraft at time of blunder, and
   c. the type of blunder, specifically, "Single Type" vs "Fast/Slow Type?"
4. Will controllers accept the PRM system as a means of safely conducting independent parallel approaches during IFR conditions to parallel runways spaced 3,000 ft apart?

2.2.3 Experimental Control Procedures – Study II

The same control procedures that were used in Study I were used in Study II. The arrival pushes that were used were a subset of the arrival pushes used in Study I. Appendix D lists the arrival pushes and approach blunders shown during Study II.

As in Study I, the approach blunders were seen by a pair of controllers which meant that one controller in the pair had an opportunity to instruct the endangered aircraft, i.e., giving one reaction time to that approach blunder. In order to determine the reaction time of both controllers, the complete set of approach blunders were presented a second time. Before beginning the second presentation, the controllers were told to change seats so that the controller monitoring the right runway would now be monitoring the left runway and vice versa. Therefore, controllers viewed an A and B version of each arrival push, as described in Section 2.1.3, Experimental Control Procedures – Study I. In order to control for effects which might be attributed to order of presentation, the nine arrival pushes were presented in a counterbalanced order. As in Study I, half of the approach blunders occurred on the right runway and half occurred on the left runway. Approximately half of the simulated arrival pushes depicted approaches to the north and half were to the south. A random number list was used to determine which approach blunders would occur on which runway and in which order of presentation. Finally, like Study I, the opportunity for approximately three speed changes was included in each arrival push.

3. METHODS

In Sections 3.1 and 3.2, respectively, the methods for Study I and Study II are discussed. The methods for both studies were similar, i.e., the same experimental set-up, including procedures and equipment, was used in both studies. The studies differed in the runway separation used in the simulation, the number of controllers involved, and the number and type of arrival pushes presented. In Section 3.3, the data collection and analysis performed in both studies is discussed.

3.1 METHODS USED IN STUDY I

3.1.1 Subjects

Twenty-five pairs of controllers, i.e., fifty controllers, participated as subjects in Study I. Each pair of controllers participated for five days. Twelve pairs of controllers were from Memphis Airport, and thirteen pairs of controllers were guest controllers, i.e, from airports where IFR (instrument flight regulations) simultaneous parallel approaches are conducted. The guest controllers had experience in the Monitor Controller position. The Memphis controllers did not have experience in the Monitor Controller position. Therefore, there were novice and experienced Monitor Controllers. This was done in order to enable a comparison of the effectiveness of the PRM system relative to experience level of controller. The experienced Monitor Controllers were from the following airports:

Atlanta, GA	Houston, TX
Charlotte, SC	Los Angeles, CA
Dallas/Fort Worth, TX	Pittsburgh, PA
Denver, CO	

3.1.2 Facilities and Equipment

3.1.2.1 The PRM Display

The display consists of a large (20" x 20"), high-resolution, color monitor. When the displays are implemented, Monitor Controllers will use the PRM displays in the Terminal Radar Approach Control (TRACON) IFR room. Associated with the displays is the same communications equipment and ancillary data displays found in the plan view displays (PVDs) in use today.

In addition to color, resolution, and size, the PRM display differs from the traditional PVD in other important ways. One feature is the ability to display a "predictor" that projects where the aircraft will be in a specified period of time, if the aircraft were to continue on its present course. The Monitor Controller can select a predictor of 0, 2, 4, 6, 8, or 10 s. (For these studies, the predictor was set for prediction of position in the next 10 s.) Another feature is the ability to expand the axis perpendicular to the runways compared with the axis along the runways, which has the effect of making lateral deviations more evident to the controller. The display's expansion capability is up to 32 times the actual dimensions. A 4:1 expansion was used during the studies.

Perhaps the most significant feature of the PRM display is the automated alerts. The system provides two alerts to the Monitor Controller on the occurrence of possible hazardous flight path deviations. When it predicts that the aircraft will enter the NTZ (no transgression zone) within the

specified time, i.e., 10 s, the aircraft symbol and accompanying data tag of the blundering aircraft changes from green to yellow, and an audible alert is delivered. The audible alert is provided by a synthesized voice (DECtalk DTC01), proclaiming "Caution!" and the flight ID of the aircraft that is deviating toward the zone. When the aircraft has penetrated the NTZ, the aircraft symbol and accompanying data tag of the blundering aircraft, as well as the aircraft symbol and accompanying data tag of the endangered aircraft, change color to red and the synthesized voice proclaims "Warning!" The Core Group of Controllers made the decision that the flight ID of the endangered aircraft was not necessary at this time since it had been previously given.

Because Monitor Controllers may not see a blunder for many months due to the relative rarity of approach blunders, the alerts are valuable. An alert will confirm that an approach blunder is occurring, allowing the controller to detect the approach blunder earlier and take prompt corrective action.

The alert system design provides two levels of alerts: (1) one alert which is very sensitive to a blunder and gives an early warning, sometimes unnecessarily, and (2) a second alert which is less sensitive and does not occur until actual penetration of the zone has occurred. As a safeguard, redundancy is built into these two alerts. As previously mentioned, the alerts are both visual and audible. Therefore, if a controller is distracted from looking at the screen, and an approach blunder occurs, the alert may not have been seen, but it may be heard. Table 3-1 summarizes the types of alerts, their meaning, and their form of visual and audible presentation.

Table 3-1

PRM Alerting System

Type of Alert	Meaning	Visual Alert	Audible Alert
Caution Alert	NTZ penetration is predicted to occur in 10 s or less	color change from green to yellow	"Caution! "(Flight ID is given)"
Warning Alert	NTZ penetration has occurred	color change to red	"Warning!"

3.1.2.2 The Testing Environment

Study I was conducted at the PRM Site at Memphis International Airport from February 5 to August 3, 1990. A photograph of the PRM Site is shown in Figure 3-1. This is a facility which was constructed for the sole purpose of Mode S data collection. For the experiment, two rooms at the site were used. Figure 3-2 depicts the configuration of the Controller Response Test Facility.

3.1.2.2.1 Experiment Control Room

The Experiment Control Room is depicted on the left side of Figure 3-2. In the Experiment Control Room were two pseudopilots, the Simulation Coordinator, and all the equipment needed to direct the pre-recorded simulation to the controllers and to record all data. There were two DEC µVAX computers executing the PRM software communicating over serial lines. The upstream VAX executed the simulation and passed data on to the downstream VAX. Each VAX sent graphics

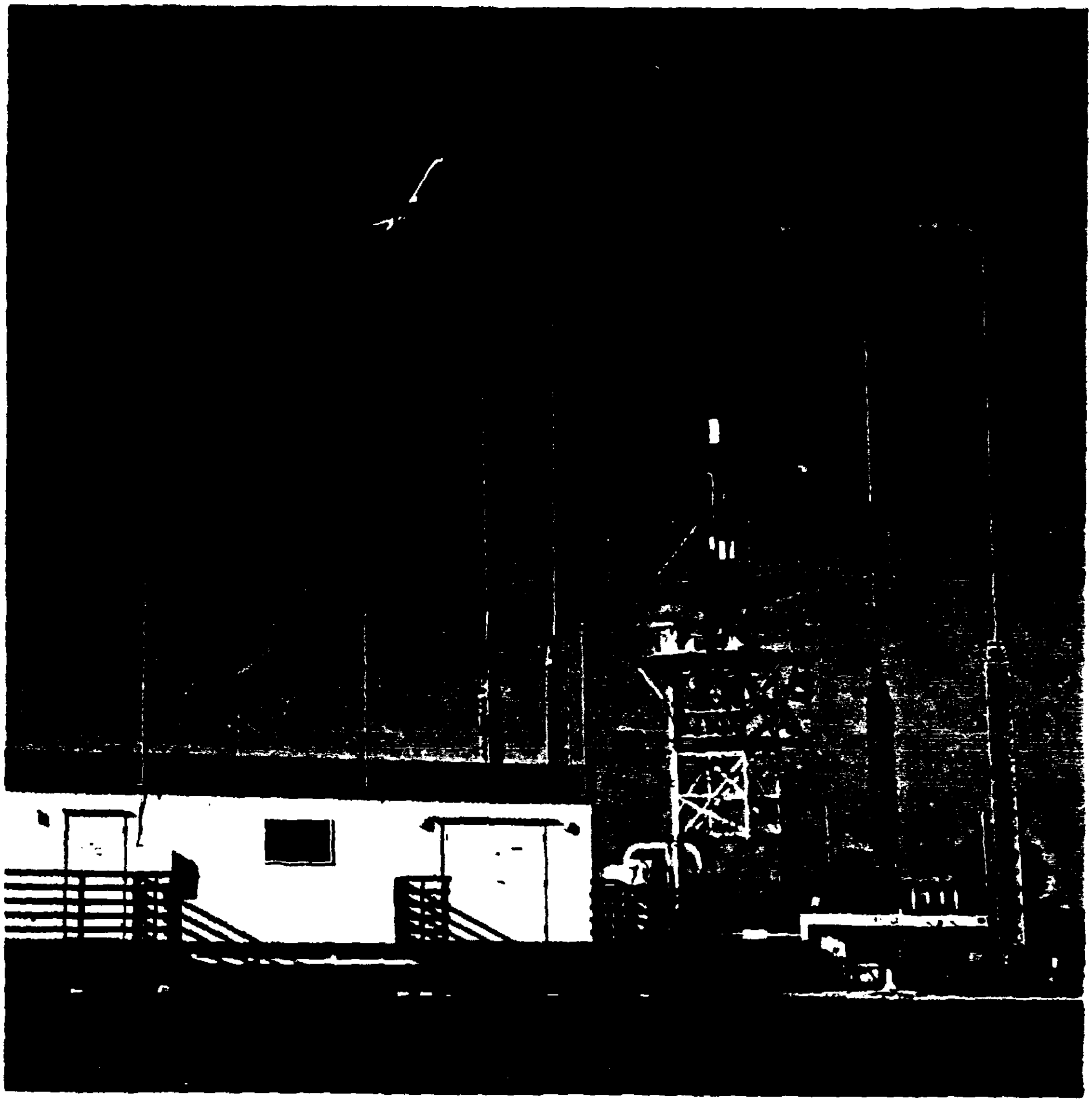

Figure 3-1. MIT Lincoln Laboratory PRM site at the Memphis International Airport.

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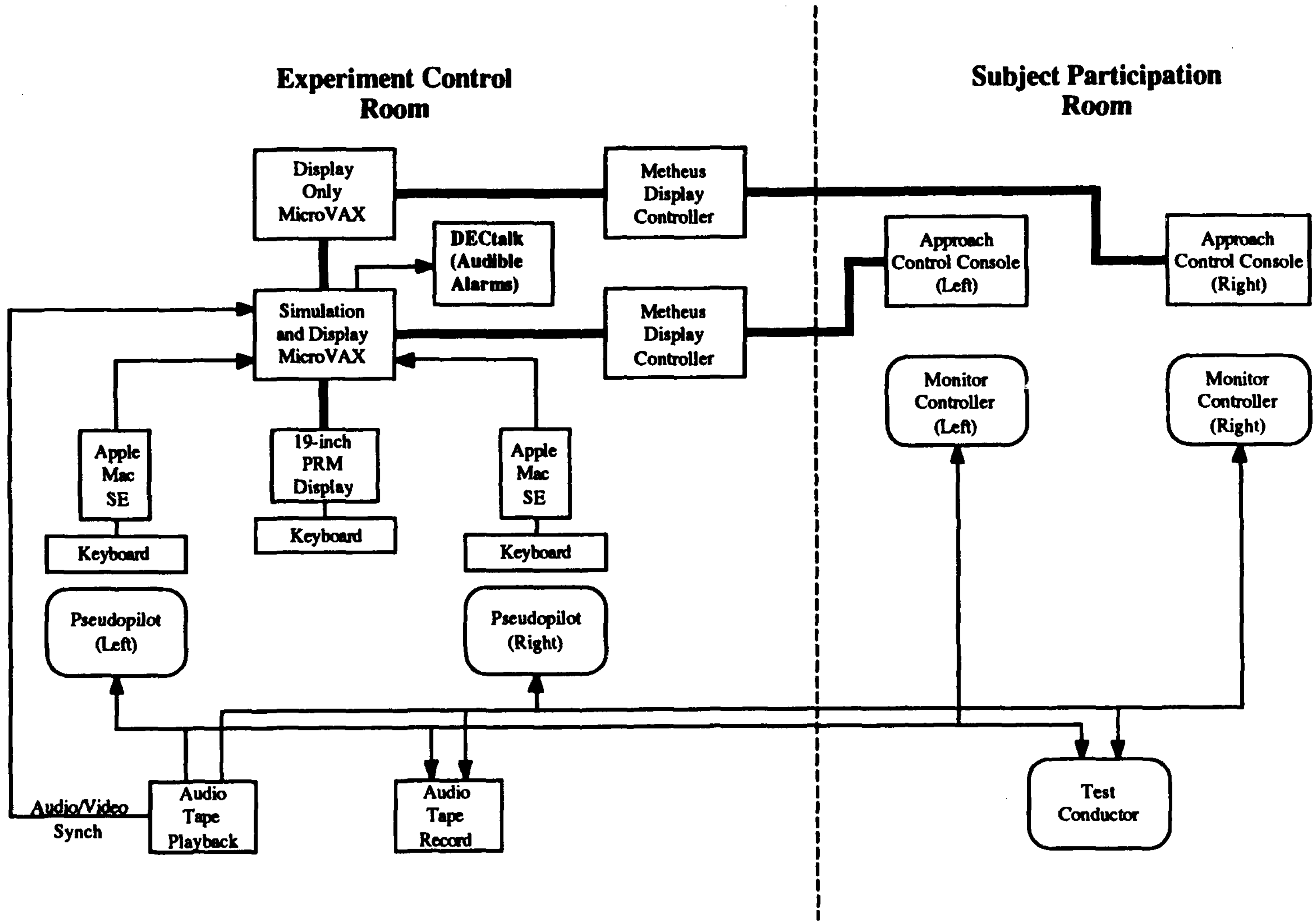

Figure 3-2. PRM Controller Response Test Facility.

commands to its own Metheus Graphics Processor which drove one of the Sony displays viewed by the controllers in the Subject Participation Room. One VAX also drove the DECtalk speech synthesizer that spoke alerts (described in Section 3.1.2.1) when aircraft neared or entered the NTZ.

In the Experiment Control Room the simulation appeared on two 19-inch VAX system monitors. The Simulation Coordinator controlled the presentation of the simulation through use of two monitors and accompanying keyboards. The simulation was observed by the pseudopilots on the same two monitors used by the Simulation Coordinator. This enabled them to see what the controllers were seeing. Each pseudopilot was responsible for one runway. He watched the screen and followed scripts which specified the pre-programmed occurrence of each approach blunder and potential speed change which the controller monitoring that runway might make.

When instructed by the controller, the respective pseudopilot entered data through use of the graphic input device on his own Macintosh PC, which displayed a left-turn compass rose, a right-turn compass rose, a speed scale, an altitude scale, and a list of the currently active aircraft flight IDs. Figure 3-3 depicts the features of the Pseudopilot Interface Screen. He would set up a left or right turn to a new heading, a new altitude, and a new speed.

The pseudopilot knew (from the script) when the next scheduled approach blunder would occur. Before it occurred, he used a mouse to set up the flight parameters that were expected to be given in the breakout instruction from the controller. When the command to break out came, the pseudopilot clicked on a send command and the new flight parameters were sent to the simulation computer after a period of time randomly selected by the software to represent delay in the cockpit. In the case of speed changes only, the new speed was sent without delay. Sometimes the controllers would order heading changes to return to the localizer. These instructions would be to aircraft depicting flight paths affected by simulated turbulent conditions or to aircraft demonstrating flight path deviations in the distraction blunder scenarios. The pseudopilot would acknowledge the instruction but would take no action, knowing the simulation was depicting a momentary deviation and that the aircraft would return to course without pseudopilot intervention.

The Audio Tape Playback was synchronized with the visual presentation of each Arrival Push. This was a pre-recorded background audio which the controller heard during each Arrival Push. It contained the standard radio transmissions that are made by local controllers and pilots on final approach. (The voice of one pilot was pre-recorded to simulate all pilot communications.)

The controller monitoring the right runway heard the audio of the right local controller and the pilot assigned to land on the right runway. The controller monitoring the left runway heard the audio of the left local controller and the pilot assigned to land on the left runway.

The Audio Tape Recorder was used to record all radio transmissions made by the subjects. This recording was also synchronized with the visual presentation of the Arrival Pushes. This recording was used to obtain the controller reaction time for each approach blunder.

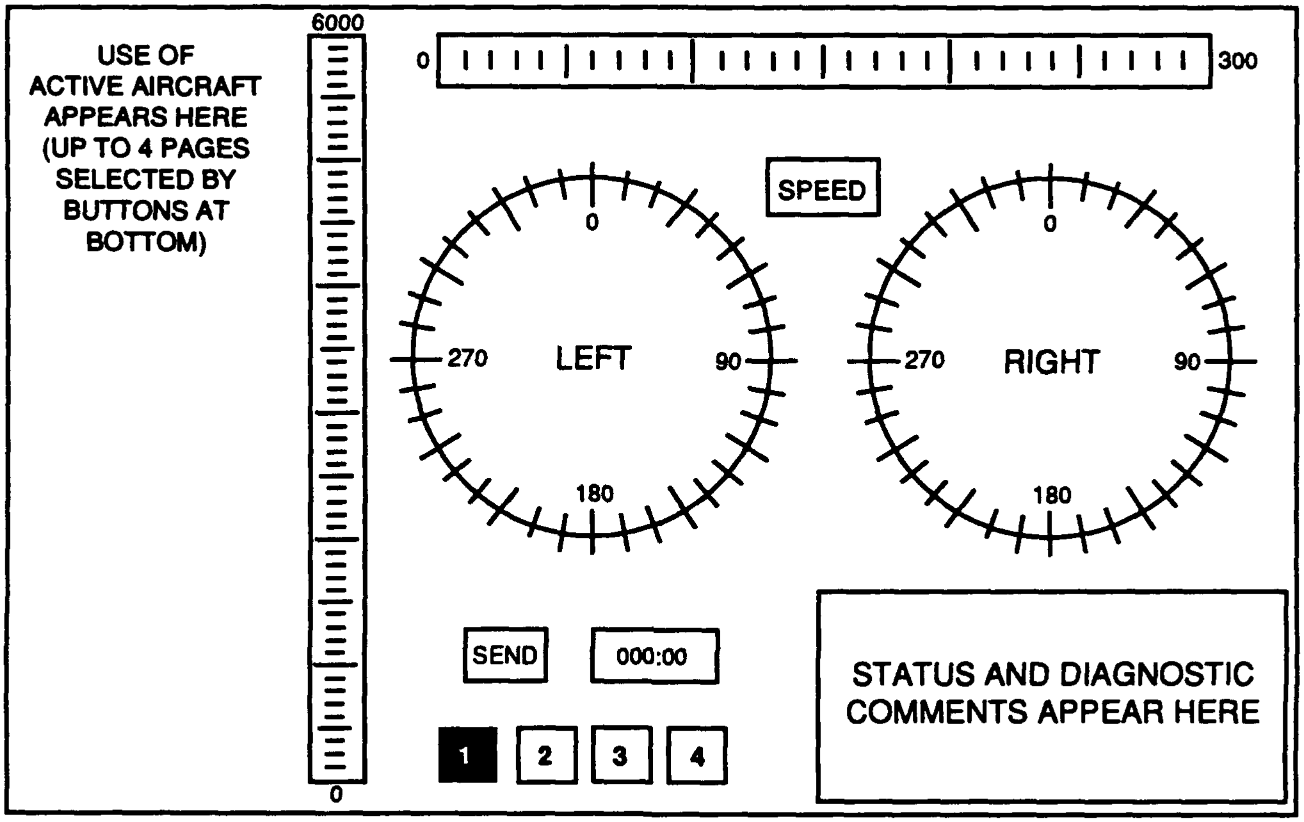

Figure 3-3. Pseudopilot Interface Screen.

3.1.2.2.2 Subject Participation Room

In an operational PRM, the PRM displays would be in the TRACON control room, near the other radar controllers managing traffic in the terminal area. During the simulation, the controllers were seated in a room containing only the equipment necessary for parallel approach monitoring. The more sterile environment, though lacking the activity and thus some of the realism of a control room, ensured that the simulation would not interfere with ongoing TRACON operations. It also allowed better control of the experiment.

The Subject Participation Room is depicted on the right side of Figure 3-2. An Approach Control Console was provided for each controller. The Console included the 20-inch SONY display. As indicated by the arrows shown in Figure 3-2, each controller was provided with a communication system which was connected to the Audio Tape Playback unit, the Audio Tape Record unit, and the appropriate pseudopilot.

Figure 3-4 is a photograph of The Subject Participation Room. During testing the lighting was controlled to simulate the dark environment of an actual TRACON.

The Test Conductor was with the controllers in the Subject Participation Room. The Test Conductor's responsibility was to ensure that all procedures were properly followed and to record any significant interactions between the controllers and anomalies in environment or Arrival Push presentations which may have affected the interpretation of the data collected. The Test Conductor was able to switch between hearing the controllers, the pseudopilots, and the Audio Tape Playback.

3.1.2.3 The Simulation

The simulation was an audio-visual presentation of approach blunders occurring during eighteen Arrival Pushes (see Appendix A and B for a list of approach blunders in each Arrival Push). The audio and visual portions of the simulation were made as realistic as possible within the constraints of the experiment. The limitations inherent in a simulation are recognized. Simulations cannot completely replicate the conditions experienced in "real life," i.e., actual air traffic control operations.

3.1.2.3.1 The Visual Portion of the Simulation

The density of traffic, type of aircraft represented, altitudes, speeds, and headings, were all based on actual traffic information from the Memphis tower staff and tapes of actual traffic at Memphis. Numerous contacts were made with Memphis Air Traffic Control personnel to verify and supplement these data.

The typical flight path for all but small General Aviation (GA) aircraft was to enter the display area on the base leg at 190 knots and slow to 170 knots on final at an altitude of 3,000 ft or 4,000 ft, depending on the runway. Small aircraft flew final at 80 or 90 knots. At a point 9 or 10 nmi out, the altitudes for both approach paths became the same and the aircraft followed a 3-deg glide slope, slowing to 140 knots over the outer marker and on down to 120 knots at the threshold. Spacing was about 3 nmi along the flight path with aircraft flying simultaneous approaches except when unusual spacing requirements temporarily precluded it. Heavy aircraft were kept 5 nmi in front of any following aircraft. All turns were made at a standard rate of 3 deg per second, and

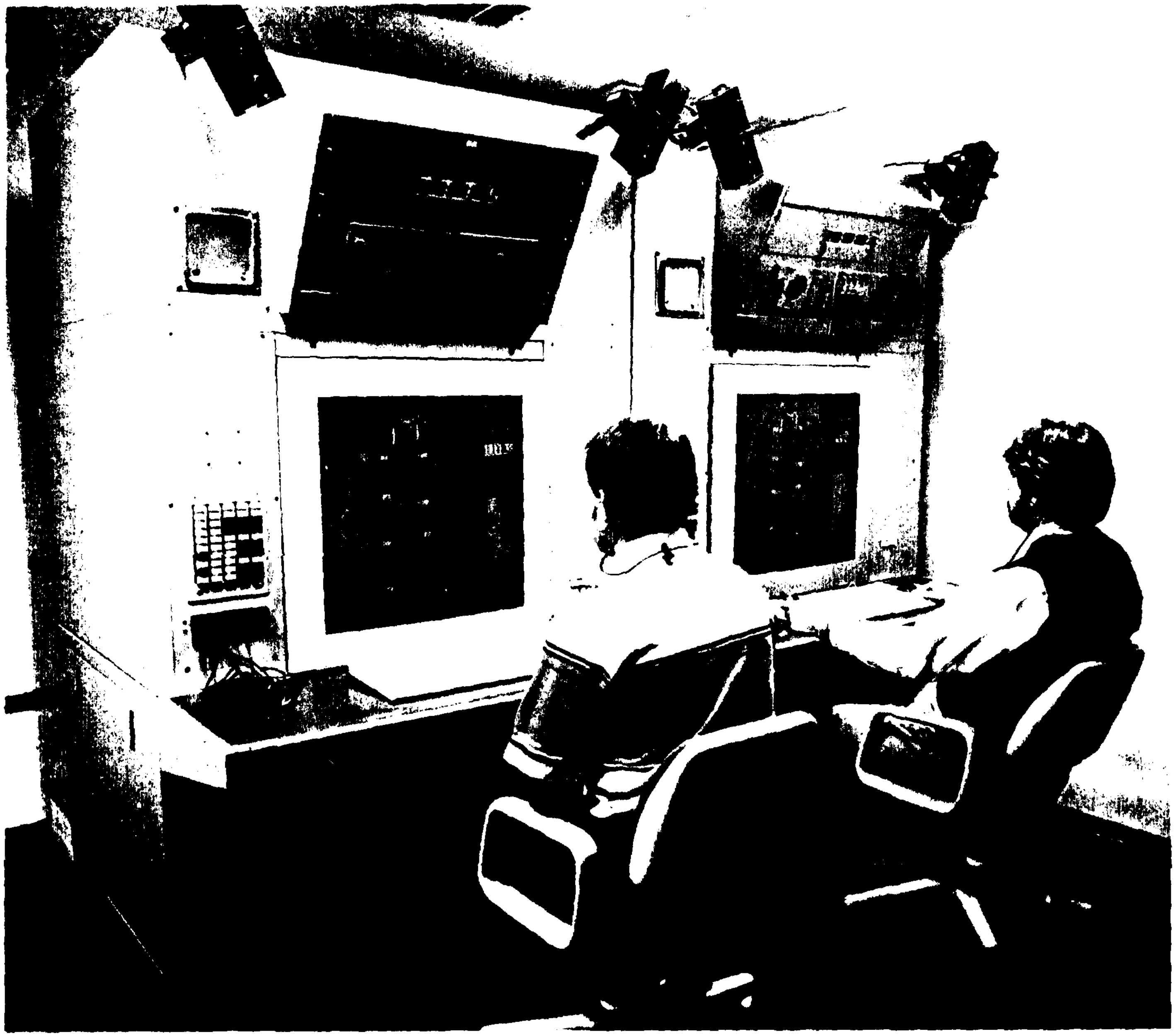

Figure 3-4. The Subject Participation Room. 215845-1

normal accelerations were at ±2.5 knots per second. Takeoff accelerations were at 5 knots per second. A sinusoidal Flight Technical Error, or wobble, was added to the aircraft's final approach path with a period of about two minutes and an amplitude at a range of 15 nmi of about 500 ft in "turbulent" conditions or 150 ft in "calm" conditions. The amplitude of the wobble decreased linearly to zero at touchdown. Appendix E shows the airline and aircraft type mix.

3.1.2.3.2 The Audio Portion of the Simulation

These recordings were made by an experienced pilot and a retired air traffic controller, in order to enhance the authenticity of the simulation. Using pre-recorded audio also enabled consistency throughout the study, i.e., all controllers heard the same audio each week.

3.1.2.4 Features of the PRM Display

The geographic maps and aircraft positions were displayed on a Sony DDM-2801C 2K x 2K color monitor driven by a Metheus Ω3720 graphics controller. The maps contained most of the features on the Automated Radar Terminal System (ARTS) video maps currently used by the Memphis TRACON. Of these, the less important map features include secondary airports, major geographical features (e.g., rivers and coastlines), obstacles, navigational reference lines, and navigational checkpoints. The more important features (refer to Figure 3-5) are the parallel runways and their extended centerlines; three parallel reference lines, 200 ft apart, running along the inside of each extended center line; and the NTZ covering a width of 2,000 ft centered between the extended centerlines. Runways not monitored were shown for reference. The extended centerlines are broken into 1-mile lengths separated by 1-mile spaces and range out to 15 miles from the runway threshold on the approach side and to 5 miles on the departure side.

An aircraft position is displayed as a small circle connected by a leader line to a three-line data block. The information displayed in the data block lines consists of (1) the flight ID, (2) the altitude and ground speed, and (3) the assigned runway code and aircraft type. There can be a projection line showing the predicted position up to 10 s into the future and a history trail of up to six past positions. This ensemble is normally green except for the predictor line, which is cyan. But when an aircraft is predicted to be inside the active NTZ within 10 s, it turns yellow and a spoken alert sounds (e.g., "Caution! Northwest twelve-sixty-four"). If the aircraft actually enters the NTZ, the aircraft ensemble turns red and a different spoken alert sounds, i.e., "Warning!" The symbology and identifier for the aircraft will also turn red if the tracking algorithm determines that it is in danger from another aircraft, or that it is approaching the wrong runway, or that its transponder has failed.

Figure 3-5 shows the PRM display in negative as seen on the Sony monitors. With runways oriented vertically on the screen, not all the screen area in the x-axis is needed to display aircraft. Therefore, five auxiliary windows are placed permanently on the right hand margin. From top to bottom, the windows are (1) the time, barometer, and stopwatch window, (2) the status window showing current zoom factors, predictor time, number of history positions, and the altitude range being displayed, as well as instructions for and status of menu selections in progress, (3) the sub-menu window required by certain main menu selections for entering data, (4) the main "point-and-click" menu, and (5) the secondary graphics window that shows the area within a blue box that can be moved around the primary graphics window. (The contents of this window are always displayed undistorted.)

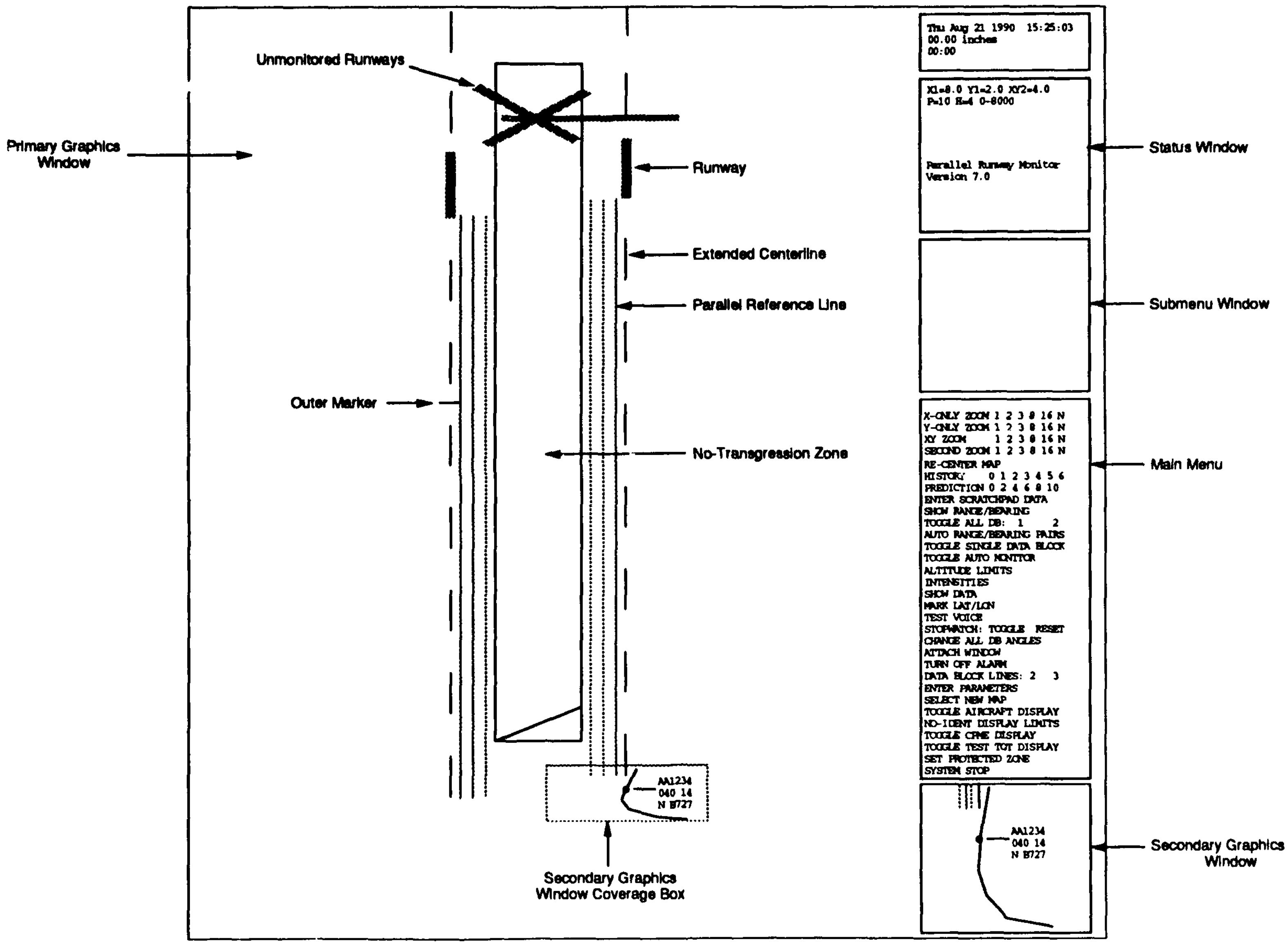

Figure 3-5. PRM Monitor Display.

3.1.2.5 The PRM Display Testing Configuration

The PRM Display Testing Configuration was determined by the PRM Working Group. During the two studies, the controllers only saw the primary graphics windows. Since the menus are only used to set up the display and do not need to be present during approach monitoring, they were omitted. The primary graphics window can be zoomed independently in the x and the y axes. There are two benefits that result from stretching the cross-runway dimension more than the other. First, cross-runway resolution is increased so that the 200-ft parallel reference lines can be seen without losing the ends of the approach path off the top and bottom of the screen. Second, cross-runway motion is exaggerated which causes the observer to be more sensitive to motion toward the NTZ. The ratio of x- and y-axis zoom factors used during the two studies was 4:1. During the two studies, the predictor line was displayed but not the history trail.

3.1.3 Study Procedures

3.1.3.1. Testing Schedule

For each pair of controllers, Monday of each week was devoted to familiarization with the PRM program, operations of the monitor display, and independent parallel approach procedures. During the week, testing was conducted within eighteen arrival pushes. Each arrival push was a simulation of approximately one hour of approach traffic, during which approach blunders occurred. Debriefing and completion of the Controller Opinion Survey occurred on Friday.

Table 3-2 shows the Subject Schedule followed for Pair #1. This particular schedule is one example of the general schedule adhered to by each pair of controllers. All controllers had a similar schedule over the five-day period. However, since arrival pushes were presented in a counterbalanced order, the schedule varied in accordance with the counterbalanced order of presentations of arrival pushes. For example, Pair #1 began testing with Arrival Push 1A, Pair #2 began testing with Arrival Push 2A, Pair #3 began testing with Arrival Push 3A, and so forth through Pair #25.

TABLE 3-2
Subject Schedule for Study I
(One Pair of Subjects Per Week)
This sample schedule was followed for Pair #1.

Day 1	Day 2	Day 3	Day 4	Day 5
Program Orientation 1 hr	Arrival Push 1A 75 min 5 blunders	Arrival Push 6A 60 min 4 Blunders	Arrival Push 2B 60 min 4 Blunders	Arrival Push 7B 60 min 4 Blunders
BREAK	BREAK	BREAK	BREAK	BREAK
Independent Parallel ILS Approach Procedures 2 hr	Arrival Push 2A 60 min 4 Blunders	Arrival Push 7A 60 min 4 Blunders	Arrival Push 3B 60 min 4 Blunders	Arrival Push 8B 60 min 4 Blunders
BREAK	BREAK	BREAK	BREAK	BREAK
Monitor Display Operations Briefing & Lab 1 to 2 hr	Arrival Push 3A 60 min 4 Blunders	Arrival Push 8A 60 min 4 Blunders	Arrival Push 4B 75 min 5 Blunders	Arrival Push 9B 45 min 3 Blunders
BREAK	BREAK	BREAK	BREAK	BREAK
Hands-on Practice & Dry-Run 2 hr	Arrival Push 4A 75 min 5 Blunders	Arrival Push 9A 45 min 3 Blunders	Arrival Push 5B 60 min 4 Blunders	Debriefing 1 1/2 hr
	BREAK	BREAK	BREAK	
	Arrival Push 5A 60 min 4 Blunders	Arrival Push 1B 75 min 5 Blunders	Arrival Push 6B 60 min 4 Blunders	

3.1.3.2 Subject Training

For each pair of controllers, Day 1 of the study was dedicated to training. The training included:

1. Program Orientation. Controllers were given background and goals of the PRM Program; a general description of the system and the display; discussion of the responsibilities of the Monitor Controller; and discussion of their role as subjects.

2. Independent Parallel Approach Procedures. Controllers were briefed on local area familiarization, approach charts and procedures, obstructions, localizer turn-on and Monitor Controller responsibility, definition of the alerts in the system, missed-approach procedure, and communications.

3. Monitor Display Operation. Controllers were given a briefing on display capabilities, menus, defaults, keyboard, and automatic alerts.

4. Dry-Run/Practical Demonstration. Controllers saw and heard a sample arrival push simulation and had the opportunity to react to the simulated approach blunders. This was for training purposes and the reaction time data were not included in the data analysis.

3.1.3.3 Monitoring Session

One pair of controllers participated each week in the Monitoring Sessions. The controllers sat next to each other, each observing the respective runway to which he/she had been assigned. One controller monitored the right parallel runway, and one monitored the left parallel runway. Each controller had a PRM Monitor Console, which housed the SONY display and keyboard. Each controller had his/her own headset on which to communicate. Each controller heard the audio of the respective local controller and pilots for the assigned runway. The information seen and heard by all pairs was the same.

Before each arrival push began, the controllers were briefed in accordance with the routine briefing experienced by a Monitor Controller. The controllers were given weather information and were told the sensor update interval at which information would be provided.

Controllers were instructed to view and listen to each arrival push and to perform the duties of a Monitor Controller. The instructions regarding breaking-out an endangered aircraft were:

> "When, in your best judgment, penetration of the NTZ is imminent, instruct aircraft on the adjacent final approach course to alter course to avoid the deviating aircraft."

The controller was instructed that he/she did not have to wait until actual penetration occurred (as signaled by the red alert warning and DECtalk). Through each controller's headset, the PRM voice alerts were heard. If the controller believed that, in his/her best judgment, penetration was imminent, he/she should respond immediately. The instructions to be given to the pilot of the endangered aircraft were: "TURN (left/right) IMMEDIATELY, HEADING (degrees), CLIMB AND MAINTAIN (altitude)."

The audio was set up so that the controller could override the local controller and speak directly to a pilot. This gave the controller quick access for giving a breakout instruction. The controller could also override the local controller and give speed adjustments if necessary. A pseudopilot acknowledged all communications from the controller.

After each arrival push was completed, the controllers completed a short debriefing questionnaire. This questionnaire was designed to elicit controller opinion on the realism of the simulation. After a 15-minute break, the next routine briefing occurred, followed by presentation of the next arrival.

3.1.3.4 Debriefing

A Controller Opinion Survey was used to obtain the opinions of the controllers on the effectiveness of the PRM system and its overall acceptability for use. On the first day of participation in the study, the pair of controllers were given a copy of the survey which was to be completed at the end of the week. This was done so that throughout the week the controllers could be mindful of the various areas in which their opinions were needed. On Friday, after all testing was completed, each controller filled out the survey. A copy of the Survey is found in Appendix F.

3.2 METHODS USED IN STUDY II

3.2.1 Subjects

Five pairs of controllers, i.e., ten controllers, participated as subjects in Study II. All ten controllers had participated in Study I and volunteered to participate in Study II. All were experienced Monitor Controllers from airports where IFR simultaneous parallel approaches are conducted. The controllers were from the following airports:

Los Angeles, CA	Pittsburgh, PA
Atlanta, GA	Houston, TX

Each pair of controllers participated for two and a half days.

3.2.2 Facilities and Equipment

The same facilities and equipment were used in both Study I and Study II. See Section 3.1.2 for details.

3.2.2.1 The Testing Environment

The study was conducted at the PRM Site at Memphis International Airport from November 26 through December 12, 1990. The PRM Controller Response Test Facility was set up in the same manner for both Study I and Study II. See Test Environment previously discussed in Section 3.1.2.2.

3.2.2.2 The Simulation

In Study I, eighteen arrival pushes were presented to the controllers. In Study II, eight arrival pushes selected from those used in Study I, were presented with the new map showing a 3,000-ft runway separation. Ten of the controllers who participated in Study I also participated in Study II. Section 2.2 explains why certain arrival pushes were eliminated in Study II. Appendix D includes the list of arrival pushes used in Study II. The same audio presentations which accompanied each visual presentation were used in both studies.

3.2.3 Study Procedures

3.2.3.1 Testing Schedule

A sample Subject Schedule is presented below. This particular schedule is one example of the general schedule adhered to by each pair of controllers. All controllers had a similar schedule over the three-day period. However, since arrival pushes were presented in a counterbalanced order, the schedule varied in accordance with the counterbalanced order of presentations of arrival pushes.

TABLE 3-3

Subject Schedule for Study II
(Two Pairs of Subjects Per Week)
This sample schedule was followed for Pair #1 and Pair #2.

Day 1	Day 2	Day 3	Day 4	Day 5
PAIR #1				
Refresher Course and Training Arrival Push 3 hr	Arrival Push 4A 75 min 5 Blunders	Arrival Push 5B 60 min 4 Blunders	Arrival Push 2A 60 min 4 Blunders	Arrival Push 4B 75 min 5 Blunders
	BREAK	BREAK	BREAK	BREAK
	Arrival Push 5A 60 min 4 Blunders	Debriefing 1 1/2 hr	Arrival Push 4A 75 min 5 Blunders	Arrival Push 5B 60 min 4 Blunders
	BREAK	PAIR #2	BREAK	BREAK
BREAK	Arrival Push 1B 75 min 5 Blunders	Refresher Course and Training Arrival Push 3 hr	Arrival Push 5A 60 min 4 Blunders	Arrival Push 1B 75 min 5 Blunders
Arrival Push 1A 75 min 5 Blunders	BREAK		BREAK	BREAK
BREAK	Arrival Push 2B 60 min 4 Blunders		Arrival Push 1A 75 min 5 Blunders	Debriefing
Arrival Push 2A 60 min 4 Blunders	Arrival Push 4B 75 min 5 Blunders		Arrival Push 2B 60 min 4 Blunders	

3.2.3.2 Subject Training

Since all ten controllers participated in Study I, extensive training in the PRM system was not necessary. A brief refresher course was given for Study II, and then controllers participated in a Training Arrival Push. Approach blunders occurred, controllers responded, but data were not included in the data analysis. This practice session provided an opportunity for the controllers to ask any questions about the simulation or testing procedures.

3.2.3.3 Monitoring Sessions

The same basic instructions were used in both studies. However, two additions were made to the instructions for Study II:

(1) Controllers were reminded that when they participated in Study I, the runway separation was 3,400 or 4,300 ft, and in this simulation, the runway separation is 3,000 ft.

(2) Controllers were told that the runways are closer together in this simulation, and the NTZ is still 2,000 ft. Therefore, the Normal Operating Zone (NOZ) is decreased. This means that it is more difficult for pilots to stay within the NOZ, and there is a greater likelihood that yellow/Caution Alerts (predicting NTZ penetration) and red/Warning Alerts (indicating NTZ penetration) will occur.

3.2.3.4 Debriefing

The Controller Opinion Surveys used in Studies I and II were similar with the following exceptions. Since in Study I the controllers had already been asked about their opinions on the Monitor Controller Functions, NTZ Alerts, and Display Information Content and Presentation, there was no need to repeat these questions in Study II. Questions in Study II included the General Acceptance section, asking controllers their opinion of the acceptability of the system when runway separation is 3,000 ft. Questions in Study II also included questions regarding the realism of the simulation. A copy of the Survey is included in Appendix G.

3.3 DATA COLLECTION AND ANALYSIS IN STUDY I AND STUDY II

In both Study I and Study II, three types of data were collected in order to evaluate the effectiveness of the system. Sections 3.3.1 through 3.3.3 define each type of data and explain how the data were collected.

3.3.1 Controller Blunder Resolution

Before acting to resolve an approach blunder, the controller pair monitoring the two approaches must first decide that a blunder is occurring. The Monitor Controller observing the blundering aircraft will instruct that aircraft to return to course. If that aircraft does not return to course or if safety does not permit waiting to see if that aircraft returns to course, the Monitor Controller observing the endangered aircraft must transmit a breakout instruction to the endangered aircraft. The sooner the instruction is transmitted to the endangered aircraft, the more time is available to maneuver the endangered aircraft out of the way. Thus, the response time of the controller monitoring the endangered aircraft is a critical element in a successful blunder resolution. Procedure sets limits on the controller response. Safe separation is lost whenever an aircraft enters the NTZ, and the controller <u>must</u> take action, usually to break out the endangered aircraft. The controller <u>may</u> direct the breakout earlier if he/she believes that the situation requires it.

Compared with existing systems, the PRM improves the radar update interval and accuracy, provides an expanded cross-track display, adds color to the display, and provides a 10-s track projection. The PRM also alerts the controller of a possible blunder by changing the color of the suspected aircraft from green to yellow, and by sounding an audible alert whenever the aircraft is projected to enter the NTZ within 10 s. These features are inextricably linked with the response time of the controller. The controller response without them was not measured.

Figure 3-6 diagrams the events occurring during a blunder resolution. One measure of the effectiveness of the system is the alert response time (ART). Measurement of this time begins when the audible Caution Alert sounds and ends when the controller begins to speak the breakout instruction to the endangered aircraft.

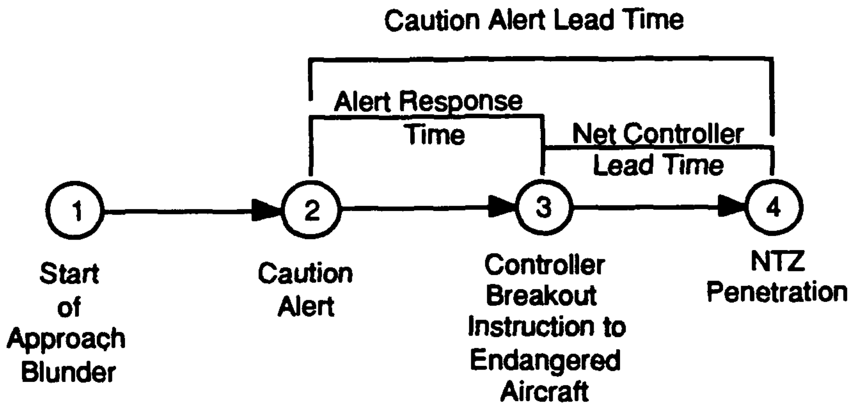

Figure 3-6. Sequence of timing events from start of approach blunder to NTZ penetration.

Because the audible alert can only sound when the target display is updated (at whatever update interval is being tested), ART, taken on its own, tends to ignore some of the advantage of the faster update interval. It is, therefore, not useful as a single measure of the controller/radar effectiveness. A better measure is how much in advance of the blundering aircraft's penetration of the NTZ the Monitor Controller began speaking. This was termed "net controller lead time." This measures the combined effects of (1) the sensor update interval, (2) the performance of the alerting algorithm, and (3) the interaction of the controller with the alert. Alert response time and net controller lead time are illustrated in Figure 3-6.

The extraction of all timing data relevant to controller response is illustrated in Figure 3-7. The upper half of the figure depicts the extraction of ART. The audible Caution Alert from the approach blunder predictor, the controller's instructions to pilots, and the pilot responses were recorded on audio tape, along with a time code that provides synchronization to the digital tape. The audio tapes were played back by a human operator. When the operator heard the audible Caution Alert which occurred prior to an approach blunder, he/she pressed a key on the keyboard to log that time. The key was also pressed to log the time when the operator heard the Monitor Controller begin the breakout instruction to the endangered aircraft. A computer program recorded each time and the difference between them. Each ART was measured three times, and the averaged value was used in the subsequent data analysis.

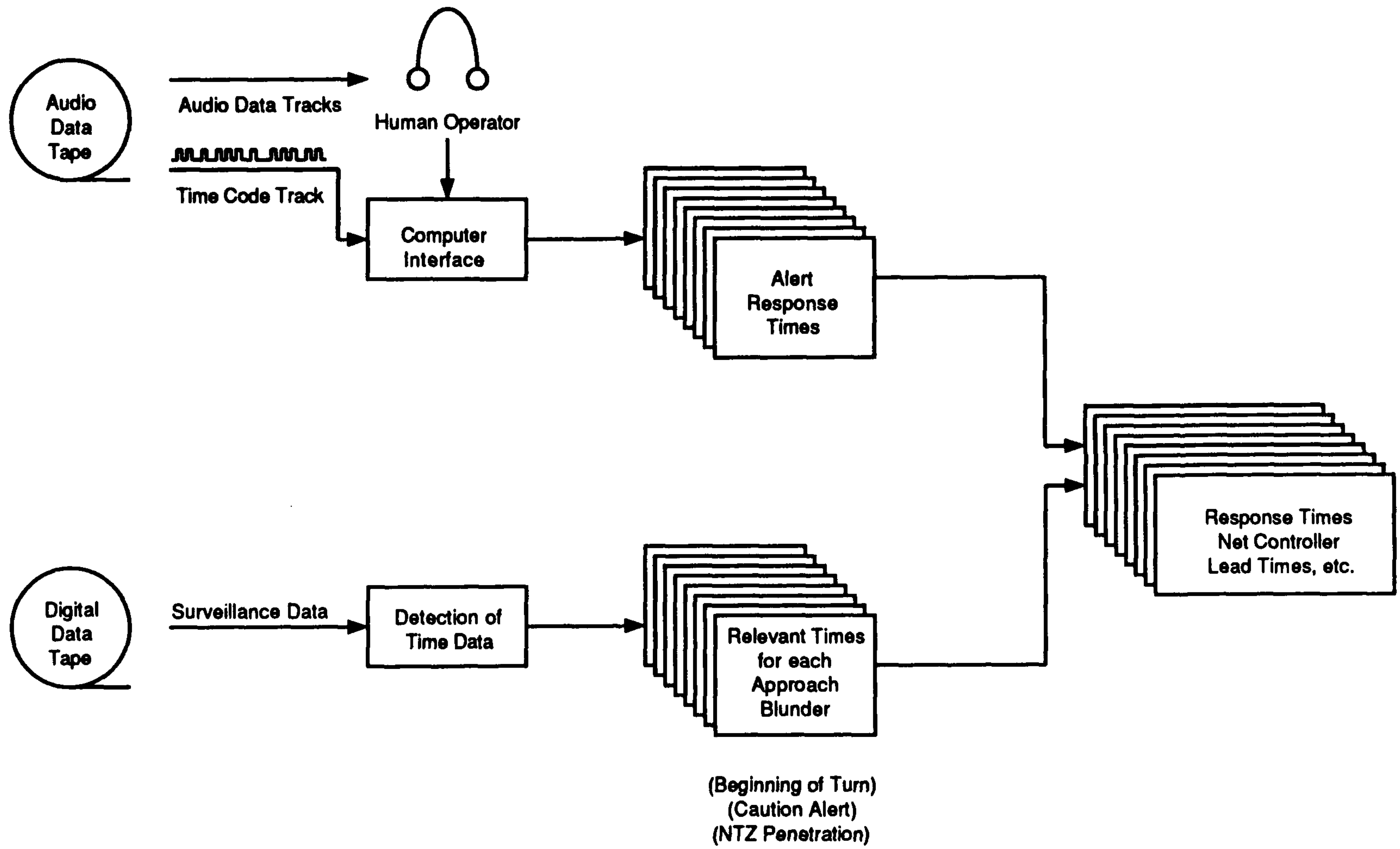

Figure 3-7. Controller Response Data Extraction.

The lower half of the figure depicts the extraction of all other pertinent time data. All track data were recorded on digital tape for later analysis. The relevant times for each approach blunder included, for example, the beginning of the turn, the time of the Caution Alert, and the time of NTZ penetration.

After ART data were extracted from the audio tapes, they were stored on a micro-VAX computer and managed by a commercially-available Relation Data Base Management System (RDBMS), named ORACLE (Version 6.0). Managing the data with an RDBMS allowed the analyst to easily and directly perform queries on the data by selecting classes of information and isolating relationships within the data.

During analysis, the data were stored in the RDBMS in table format. The controller response database consists of three tables: (1) the BLUNDER table contains a summary description of each of the approach blunders, (2) the CONTROLLER_RESPONSE table contains the measured controller ARTs for each of the tested approach blunders described in the BLUNDER table, and (3) the CAUTION_ALERT table contains the lead time (time from Caution Alert to crossing into the NTZ) for each approach blunder. The analyst used all three tables to isolate relationships of interest and obtain the measured data for analysis. Appendices H, I, and J list examples of database queries and replies. SPSS, a comprehensive, integrated system for statistical data analysis [8], was used to analyze the ART data.

As discussed in Section 2, the major design of the studies was a within-subject, paired-sample design. Therefore, paired-sample t-testing was used to assess the significance of the difference between mean ARTs.

The ART of each individual under one condition was compared to the ART of the same individual under another condition. In each case, only one variable was manipulated in each condition. For example, in the case of sensor update interval, the ART of Controller #1 in condition 1.0-s sensor update interval, "Single Type" blunder, near range, calm flight path was compared to the ART of Controller #1 in condition 2.4-s sensor update interval, "Single Type" blunder, near range, calm flight path. Thus, the comparison is of the same controller's performance when the only variable changed was the sensor update interval; the other variables were held constant.

In the analysis of paired data, for each pair of cases, the difference in the responses is calculated. The statistical procedure used tested the hypothesis that the mean difference in the population is zero. The statistic used was

$$t = \frac{\overline{D}}{S_D/\sqrt{N}} \tag{1}$$

$\overline{D}$ is the observed difference between the two means and S_D is the standard deviation of the differences of the paired observations. The sampling distribution of t, if the differences are normally distributed with a mean of zero, is Student's t with N-1 degrees of freedom, where N is the number of pairs.

The test result provides a probability value that tells us the likelihood that the difference between means is attributable to chance. In general, probability values of .05 or less are considered "significant." A probability value of .05 means the likelihood of this effect (the difference between

means) occurring by chance, due to sampling error, is 5 in 100. A probability criteria of .05 or less means that we will reject the null hypothesis, i.e., reject that there is no significant difference between means, when the probability value is .05 or less.

When multiple comparisons are made, such as, performing a succession of within-subject t-tests, each result on its own is well founded. However, inherent in performing a succession of analyses is the fact that as one increases the number of comparisons the likelihood of finding "significance" increases.

In an attempt to be conservative in interpreting results, an adjustment in the test levels can be made. This adjustment reflects the fact that, just on chance, a proportion of the tests will be flagged as significant. However, one should be aware that in doing so we will err on the conservative side, i.e., we will tend to screen out comparisons that really are significant. One way to make this adjustment is to use the Bonferroni Multiple Testing Procedure [9].

In interpreting the results of the within-subject comparisons, instead of using a per-comparison probability level of .05, a per-comparison level of .05/C is used (where C is the total number of planned comparisons). Use of this procedure causes one to err on the conservative side, i.e., rejecting probability values that meet the criteria of .05 or less but do not meet the new criteria resulting from .05/C. This procedure was applied to the probability values resulting from the analysis of within-subject data reported for Study I and II. Appendix K lists the number of within-subject t-test comparisons made in each analysis area and provides the adjusted probability criteria.

As discussed in Section 2, in studying the effects of the variables "controller experience level" and "runway separation," a between-subject independent-sample design was used. The statistic used was

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{S_1{}^2/N_1 + S_2{}^2/N_2}} \tag{2}$$

$\overline{X_1}$ is the sample mean of Group 1, $S_1{}^2$ is the variance, and N_1 is the sample size.

3.3.2 False Breakout Rate

A false breakout is a situation in which a controller unnecessarily initiated a breakout, based on the behavior of an aircraft that suggested that a deviation would cause penetration of the NTZ, when in fact it remained in the normal operating zone. There is concern that the presence of a yellow/audible Caution Alert (predicting NTZ penetration in 10 s or less if the aircraft remains on its present course) may cause an unacceptable number of false breakouts. At worst, an excessive number of false breakouts could offset the potential capacity gains resulting from independent parallel approaches.

False breakouts were studied in the following ways. In Study I, nuisance Caution Alerts were generated in three ways: (1) simulated turbulence, (2) simulated TNSE, and (3) deviations caused by aircraft that were scripted to be distractions to the controllers. Scripted distractions were situations in which all aircraft were depicted as flying routinely, but one aircraft suddenly had an erratic flight path either toward or away from the NTZ. In Study II, nuisance Caution Alerts were generated in one

way, i.e., simulated TNSE. In both studies, data were collected on each false alert breakout resulting from each nuisance Caution Alert, and the False Breakout Rates were calculated.

3.3.3 Controller Opinion

Controller Opinion Survey forms were developed with the input of the Core Group of Controllers. The surveys for Study I (Appendix F) and Study II (Appendix G) were used to obtain the opinions of the controllers on the effectiveness of the PRM system and its overall acceptability for use.

4. RESULTS OF STUDY I

In Section 4, the results of Study I are presented. Section 4.1 focuses on controller response to simulations of approach blunders presented at 1.0-s and 2.4-s sensor update intervals, 3,400 ft runway separation. Section 4.2 focuses on controller response to simulations of approach blunders presented at 4.8-s sensor update interval, 3,400-ft vs 4,300-ft runway separation.

In the above mentioned sections, the effects of the following variables on the Alert Response Time (ART) of controllers are reported and interpreted: sensor update interval, deviation angle, aircraft range from the runway threshold, flight path conditions, type of approach blunder, runway separation (in the case of 4.8-s sensor update interval), and controller experience level. These variables were defined in Section 2.1.1.

Throughout Section 4, there is a brief description of each analysis performed. ART results which are statistically significant are underlined. Throughout Sections 4.1.1 through 4.1.6, 4.2.1 and 4.2.2, and 4.4.1 through 4.4.4, within-subject comparisons are made. The probability criteria set for determining a significant difference between means is a probability value of .001 or less (computation of probability criteria is discussed in Section 3.3.1). Section 4.1.7 and 4.3 document between-subject comparisons made. The probability criteria set for determining a significant difference between means is a probability value of .05 or less.

False Breakout results are discussed when applicable. Results of the Controller Opinion Survey used for Study I are presented in Section 4.5.

Before delving into the details of each analysis area, an "Overview of Findings" is presented. This gives the reader a quick look at the answers to the research questions (listed in Section 2.1.2) asked in Study I. Reference is made to the section in which greater detail on findings can be found.

Overview of Findings

Question 1: How does sensor update interval affect reaction time? This will give us information needed to decide whether a 1.0-s or 2.4-s sensor update interval is required for system effectiveness at 3,400 ft runway separation.

Findings: Whether the sensor update interval was 1.0-s or 2.4-s, mean ART did not differ significantly, when looking at all "Single Type" approach blunders combined, i.e., 2.7 s and 2.8 s, respectively. In either case, on average, the controllers began the breakout instruction before the blunderer penetrated the NTZ. However, while the mean ART of both update intervals does not differ significantly, the faster update interval does provide increased advance warning that translates into a greater miss distance between aircraft. (For details, see Section 4.1.1.) In addition, the faster sensor update interval resulted in a lower false breakout rate. (For details, see Section 4.1.8.)

Question 2: When the runway separation is 3,400 ft, are there differences in reaction time attributable to:

a. the angle of the deviation of the approach blunder,

b. the range (nmi from the runway threshold) of aircraft at time of blunder,

c. the flight path condition during the approach blunder,

d. the type of approach blunder, for example, one involving one aircraft at a fast speed deviating toward another aircraft at a slow speed, and

e. controller experience level?

Findings:

a. Yes, whether the sensor update interval was 1.0 s or 2.4 s, mean ART differed significantly due to deviation angle. The mean ART for 30-deg approach blunders was approximately 1.0 s faster than for 15-deg approach blunders. (For details, see Section 4.1.3.).

b. Yes, when comparing approach blunders occurring at far range vs near range, 15-deg deviation angle: whether an approach blunder was presented at 1.0-s or 2.4-s sensor update interval, the mean ART was approximately 1.0 s slower for approach blunders at the far range. However, there was no significant difference in ART for 30-deg approach blunders, when comparing far vs near ranges. (For details, see Section 4.1.4.)

c. No, for approach blunders with 30-deg deviations, no significant difference was found in mean ART when comparing blunders which occurred in calm vs turbulent flight path conditions. (For details, see Section 4.1.5.)

d. No, in general, mean ART did not appear to vary greatly as a function of approach blunder type. (For details, see Section 4.1.6.)

e. Yes, experienced Monitor Controllers responded with a mean ART of approximately 1.0 s slower than the controllers who had no previous experience as Monitor Controllers. (For details, see Section 4.1.7.)

Question 3:	Are there differences in reaction time attributable to runway separation in feet from centerline to centerline? The specific case tested was the presentation of approach blunders at the 4.8-s sensor update interval with 3,400-ft vs 4,300-ft runway separation.
Findings:	Yes, mean ART was significantly faster when the runway separation was increased from 3,400 ft to 4,300 ft. The mean ART in the 4,300-ft runway separation condition was 2.6 s faster than the mean ART in the 3,400-ft runway separation condition. (For details, see Section 4.3.)
Question 4:	When runway separation is 4,300 ft and the sensor update interval is 4.8 s, are there differences in reaction time attributable to: a. deviation angle, b. range, c. flight path condition, and d. type of approach blunder?
Findings:	a. No, whether the deviation angle was 15 deg or 30 deg the mean ART did not differ significantly. In the case of 15-deg deviation angle, mean ART was 0 s, and in the case of 30-deg deviation angle, mean ART was 1.0 s. (For details, see Section 4.4.1.) b. Yes, when comparing 30-deg deviation angle, occurring at far range vs near range: whether an approach blunder was presented at 1.0-s or 2.4-s sensor update interval, mean ART was significantly slower (i.e., approximately 2.5 s slower) for approach blunders at the far range. In the 15-deg deviation angle condition, only near range deviations were included. Therefore, no comparison could be made of 15-deg approach blunders, near vs far ranges. (For details, see Section 4.4.2.) c. No, mean ART did not differ significantly when comparing calm vs turbulent flight path conditions. In both calm and turbulent conditions, the mean ART was 0 s. (For details, see Section 4.4.3.) d. No, mean ART did not differ significantly when comparing "Single Type" vs "Fast/Slow Type" approach blunders (15-deg deviation angle, near range). In either case, the mean ART was approximately 0 s. (For details, see Section 4.4.4.)
Question 5:	Will controllers accept the PRM system as a means of safely conducting independent parallel approaches during IFR conditions to parallel runways spaced 3,400 ft apart?
Findings:	Yes, controllers were unanimous in their enthusiasm for the PRM system. They all reported that with the PRM system, with its high resolution color display and automated alerts, they could monitor the final better than with the current ARTS (Automated Terminal Radar System). (For details, see Section 4.5).

4.1 RESPONSES TO SIMULATIONS OF APPROACH BLUNDERS PRESENTED AT 1.0-S AND 2.4-S SENSOR UPDATE INTERVALS, 3,400-FT RUNWAY SEPARATION

4.1.1 Overall Effect of Sensor Update Interval

In order to assess the effects of the 1.0-s and 2.4-s sensor update intervals on ART, the responses of the controllers to the eight "Single Type" approach blunders presented at each of the respective sensor update intervals were analyzed. Results from the "Fast/Slow Type" and "Distraction Type" blunders are reviewed in Section 4.1.6. They are reviewed separately because of the unique characteristics of these approach blunders.

ART results are presented in Table 4-1 for the 1.0-s and 2.4-s sensor update intervals. For each sensor update interval, the mean ART, standard deviation (sd), and minimum and maximum ART values are reported.

Table 4-1

A Comparison of ART During Simulations of Simultaneous Parallel Approaches to Runways with 3,400-ft Separation

Update Interval	1.0 s	2.4 s
# of Responses	392	392
Maximum ART	16.3	11.5
Minimum ART	-2.8	-2.7
sd	1.9	1.9
Mean ART	2.7	2.8

T-test results indicate t = -1.02, P =.309 (degrees of freedom (df) = 391). Since the probability that the difference in mean ART is >.001, the null hypothesis is accepted, i.e., no significant difference was found between the mean ART of 1.0-s vs 2.4-s sensor update interval. The conclusion that follows is that regardless of the speed at which the information was provided to the controller (limited to the two update intervals tested), the individual controller's mean ART did not change significantly.

Although the use of these two sensor update intervals did not cause a significant change in mean ART, there are two additional factors to consider. These factors are (1) the amount of information, provided by each of the sensor update intervals, on which the controller can base the breakout decision, and (2) the Net Controller Lead Time (defined in Section 3.3.1).

Let us consider the amount and sequence of information provided by each of the two sensor update intervals. This is graphically represented in Figures 4-1a and b. Looking at Table 4-1, we see that on average in the 1.0-s sensor update interval condition, controllers responded at 2.7 s. As shown in Figure 4-1a, a Caution Alert is received at 0-s elapsed time, a revised aircraft position is seen at 1.0-s elapsed time, and another revised aircraft position is seen at 2.0-s elapsed time. Then, on average, the controller made a decision to break out the endangered aircraft at approximately 2.7-s elapsed time. Therefore, the decision was generally based on information from three sequential sensor updates.

On average in the 2.4-s sensor update interval condition, controllers responded at 2.8 s. As shown in Figure 4-1b, a Caution Alert is received at 0-s elapsed time and one revised aircraft position is seen at 2.4-s elapsed time. Therefore, in the 2.4-s sensor update interval condition, on average, the controller's decision was based on information from two sequential sensor updates, while in the 1.0-s sensor update interval condition, on average, the controller's decision was based on information from three sequential sensor updates.

Although an extra update was obtained with the more frequent sensor update interval, data show that it still took almost 3.0 s to make the decision. It appears that regardless of how quickly the information was presented (within the confines of 3,400-ft runway separation, 1.0-s vs 2.4-s sensor update interval), there is a limit to how quickly the human operator can perform the task at hand. The following steps are needed in taking corrective action, i.e., initiating the breakout communication to the endangered aircraft; perceive the alert, analyze the information presented, decide to take action, and then begin to initiate a verbal response.

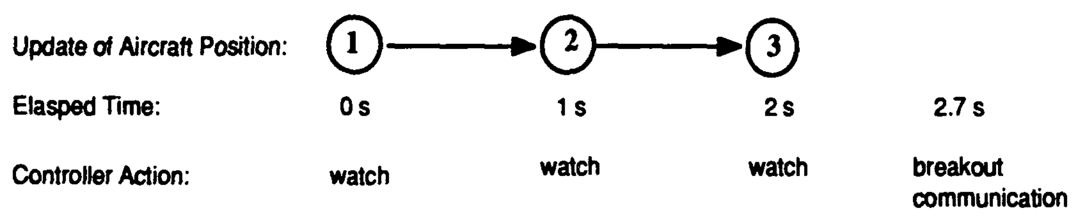

Figure 4-1a. Sequence of Timing Events during 1.0-s Sensor Update Interval.

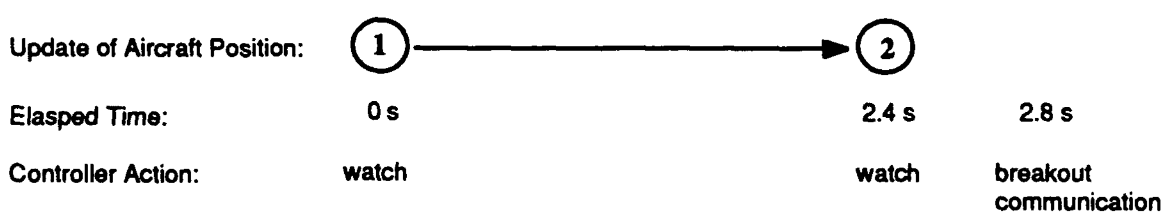

Figure 4-1b. Sequence of Timing Events during 2.4-s Sensor Update Interval.

In the case of the 2.4-s sensor update interval condition, if the controllers had waited for the "Aircraft Position #3" (as was the case in the 1.0-s sensor update interval condition), the controllers would have had to wait until 4.8 s had elapsed. It is obvious that the controllers judged that it would be too long to wait before taking action. Perhaps they would have liked another update, but considering the severity of the situation, i.e., impending penetration of the NTZ and endangering another aircraft, they chose not to wait.

4.1.2 Net Controller Lead Time

Let us consider the Net Controller Lead Time provided by the sensor update intervals. Table 4-2 presents mean values of net controller lead time. The values are a measure of how much in advance of the blundering aircraft entering the NTZ the controller broke out the endangered aircraft. Net Controller Lead Time is depicted in Figure 3-6. It is calculated by subtracting the controller ART from the Caution Alert lead time (CALT). CALT is the time between the first PRM Caution Alert during a blunder and when the blundering aircraft enters the NTZ. For the study, CALT was measured from digital recordings of the blundering aircraft. Given that the blundering aircraft went on to enter the NTZ and continued to endanger the other aircraft, increases in controller lead time translate directly to more time for the endangered aircraft to maneuver clear. The time is a reasonable measure of how much advance warning the system (radar, displays, predictors, controller training, and procedures) gives to the endangered aircraft. The faster update intervals give earlier warnings. Table 4-2 shows the mean values of all the times shown in Figure 3-6.

Table 4-2

Net Controller Response Lead Time
Mean Seconds Prior to NTZ Penetration at 3,400-ft Runway Separation

Update Interval	1.0 s		2.4 s		4.8 s	
Blunder Angle	15 deg	30 deg	15 deg	30 deg	15 deg	30 deg
Caution Alert Lead Time(s)	7.4	5.0	6.2	3.9	4.2	1.7
Alert Response Time(s)	3.1	2.2	3.3	2.3	4.0	3.7
Net Lead Time(s)	4.3	2.8	2.9	1.6	-0.2	-2.0

In summary, it appears that regardless of sensor update interval, the mean ART of controllers remained basically the same. However, the 1.0-s sensor update condition did provide one additional update of the aircraft position. It is not know if this additional update made the controllers feel more confident in their decision to breakout the endangered aircraft. The advantage of the faster update interval is the increased amount of advance warning given by the 1.0-s vs 2.4-s sensor update interval. When the ART in response to both update intervals is similar, but the faster update interval provides increased advance warning, this translates into a greater miss distance (approximately 120 ft per second) between aircraft when the faster update interval is used.

4.1.3 Effect of Deviation Angle

In order to assess the effect of deviation angle in the 1.0-s and 2.4-s sensor update interval conditions, the responses of the controllers to the eight "Single Type" approach blunders presented at each of the respective sensor update intervals were analyzed.

ART results are presented in Table 4-3 for approach blunders with both a 15-deg and 30-deg deviation angle. The "Fast/Slow Type" and "Distraction Type" approach blunders were omitted from this table since these two types of blunders did not include all the combinations of blunder angles, ranges, and flight path conditions that were included in the "Single Type" of approach

blunders. The "Single Type" conditions represent a full data set, allowing for a balanced comparison of 15-deg vs 30-deg deviation angle; i.e., every approach blunder tested in "Single Type," 15-deg deviation angle was also tested in "Single Type" 30-deg deviation.

Table 4-3

A Comparison of ART for "Single Type" Approach Blunders 15-deg vs 30-deg Deviation Angle (3,400-ft Runway Separation)

Update Interval	1.0 s		2.4 s	
Deviation Angle	15 deg	30 deg	15 deg	30 deg
# of Responses	198	198	194	194
Maximum ART	9.7	6.8	11.5	7.4
Minimum ART	-2.6	-2.4	-2.4	-2.7
sd	2.2	1.4	2.2	1.5
Mean ART	3.1	2.2	3.3	2.3

Results indicate that at both sensor update intervals, the mean ART for approach blunders with a 30-deg deviation angle are approximately 1.0 s faster than approach blunders with 15-deg deviation angle. With a 30-deg deviation angle, penetration of the NTZ occurred more rapidly than with a 15-deg deviation angle. There was less time before NTZ penetration; therefore, the controller reacted more rapidly.

Two paired-sample t-tests were performed to assess the effect of ART attributable to the deviation angle, within each of the sensor update interval conditions:

(1) 1.0-s sensor update interval, 15-deg vs 30-deg deviation angle:

Results indicate that $t = 6.81$, $P = .000$ ($df = 197$). Since the probability is <.001, the null hypothesis is rejected; i.e., there is a significant difference in mean ART due to deviation angle. This is a very strong effect. The probability of this effect occurring by chance due to sampling error is less than 1 in 1,000.

(2) 2.4-s sensor update interval, 15-deg and 30-deg deviation angle:

Results indicate that $t = 6.10$, $P = .000$ ($df = 193$). Like the 1.0-s sensor update interval condition, the 2.4-s sensor update interval condition probability is <.001, and the null hypothesis is rejected. Therefore, there is a significant difference in mean ART due to deviation angle. This too is a very strong effect. For both sensor update intervals the probability of this effect occurring by chance due to sampling error is less than 1 in 1,000.

The results indicate that in both sensor update interval conditions (1.0 s and 2.4 s), the angle of the deviation was shown to make a significant difference in the mean ART. Controllers responded to approach blunders with a 30-deg deviation angle with greater speed (approximately 1.0 s faster) than a 15-deg deviation angle.

The reason for this additional speed in a response to a 30-deg blunder is probably two-fold. First, a 30-deg blunder is quite severe and requires immediate action, while with a 15-deg blunder, the controller can wait a little longer to see how the situation develops and then make a decision on

whether or not a breakout is necessary. Second, the expanded view, used to enable quick detection of deviations, exaggerates the angle of the deviation. This causes a 30-deg deviation to appear to be even more severe, resulting in increased speed of response.

4.1.4 Effect of Approach Blunder Range

The question arises: Since the results on deviation angle indicate that controllers responded to approach blunders with a 30-deg deviation angle approximately 1.0 s faster than with a 15-deg deviation angle, then how does the added variable of the range at which the approach blunder occurred affect ART? For example, is the ART to all approach blunders with a 15-deg deviation angle approximately 3.0 s or does the ART vary with the range at which the approach blunder occurs?

ART results are presented in Table 4-4 for approach blunders with a 15-deg and 30-deg deviation angles when the range of the approach blunder was near (2 to 4 nmi) vs far (8 to 12 nmi) from the runway threshold. ART for both 1.0-s and 2.4-s sensor update intervals in the "Single Type" of approach blunder are shown. Again, "Fast/Slow Type" and "Distraction Type" approach blunders were omitted.

Table 4-4

A Comparison of ART for "Single Type" Approach Blunders, 15-deg vs 30-deg Approach Blunder Angle, and Approach Blunder Ranges of Near vs Far (3,400-ft Runway Separation)

Update Interval	1.0 s				2.4 s			
Deviation Angle	15 deg		30 deg		15 deg		30 deg	
Blunder Range	near	far	near	far	near	far	near	far
# of Responses	99	99	99	99	99	99	96	96
Maximum ART	9.8	8.5	5.9	6.8	9.8	8.5	5.7	7.4
Minimum ART	-2.6	0.4	-2.4	-1.9	-2.6	0.4	-2.7	-2.7
sd	2.3	2.0	1.6	1.3	2.2	2.0	1.5	1.4
Mean ART	2.7	3.5	2.1	2.4	2.7	3.9	2.3	2.2

Four paired-sample t-tests were performed to assess the effect of range on the mean ART to approach blunders within 15-deg and 30-deg deviation angles.

(1) 1.0-s sensor update interval, 15-deg deviation angle, near vs far range:

Results indicate that $t = -3.59$, $P = .001$ ($df = 98$). Since the probability is .001, the null hypothesis is rejected; i.e., there is a significant difference in mean ART due to the range at which the approach blunder with a 15-deg deviation angle occurred during the 1.0-s sensor update interval. This is a very strong effect. The probability of this effect occurring by chance due to sampling error is approximately 1 in 1,000. In the far range approach blunders, the ART was approximately 0.8 s longer than during the near range approach blunders.

(2) 1.0-s sensor update interval, 30-deg deviation angle, near vs far range:

Results indicate that $t = -1.48$, $P = .143$ ($df = 98$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to the range at which the approach blunder with a 30-deg deviation angle occurred during the 1.0-s sensor update interval.

(3) 2.4-s sensor update interval, 15-deg deviation angle, near vs far range:

Results indicate that $t = -4.42$, $P = .000$ ($df = 98$). Since the probability is <.001, the null hypothesis is rejected; i.e., there is a significant difference in mean ART due to the range at which the approach blunder with a 15-deg deviation angle occurred during the 2.4-s sensor update interval. This is a very strong effect. The probability of this effect occurring by chance due to sampling error is less than 1 in 1,000. This result is compatible with the results found for the same deviation angle and range in the 1.0-s sensor update interval condition.

(4) 2.4-s sensor update interval, 30-deg deviation angle, near vs far range:

Results indicate that $t = .56$, $P = .579$ ($df = 95$) . Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to the range at which the approach blunders with a 30-deg deviation angle occurred during the 2.4-s sensor update interval.

In summary, whether an approach blunder was presented at 1.0-s or 2.4-s sensor update interval, when the deviation angle was 15 deg, the ART was significantly slower for approach blunders at far range than at near range. It may be that this effect occurred in the approach blunders with a 15-deg deviation angle and not in the 30-deg deviation angle, since with the more severe deviation angle of 30 deg, the controllers know that they must act as quickly as possible regardless of the range of the blunder. A question is: Why on the 15-deg approach blunders would ART be slower when the approach blunder occurs further from the runway threshold? It may be because at the far range the aircraft are not stable on the localizer, TNSE is greater, and more Caution Alerts are occurring. The controllers may have been waiting for greater flight path stabilization and, therefore, waited longer after the Caution Alert was received at the far range vs near range.

4.1.5 Effect of Flight Path Condition

The next area analyzed was the effect of the simulated flight path condition on ART during the presentation of approach blunders at the two sensor update intervals. Since it was found that the responses to approach blunders with a 30-deg deviation angle did not differ significantly by range (see Section 4.1.4), near and far range 30-deg deviation blunders were pooled, and the effect of calm vs turbulent flight path were analyzed.

ART results are presented in Table 4-5 for approach blunders with 30-deg deviation angle, calm vs turbulent flight path conditions. ART for both 1.0-s and 2.4-s sensor update intervals in the "Single Type" approach blunder are shown.

Table 4-5

A Comparison of ART for "Single Type" Approach Blunders, 30-deg Deviation Angle, Calm vs Turbulent Flight Path Conditions (3,400-ft Runway Separation)

Update Interval	1.0 s		2.4 s	
Flight Path	Calm	Turbulent	Calm	Turbulent
# of Responses	99	99	96	96
Maximum ART	6.8	5.9	5.7	6.4
Minimum ART	-2.1	-2.4	-2.7	-2.7
sd	1.6	1.3	1.3	1.5
Mean ART	2.2	2.3	2.2	2.3

Two paired-sample t-tests were performed to assess the effect of flight path condition within ART to approach blunders with 30-deg deviation angle.

(1) 1.0-s sensor update interval, 30-deg deviation angle, calm vs turbulent flight path conditions:

Results indicate that t = -.66, P = .513 (df = 98). Since the probability is >.001, the null hypothesis is accepted, i.e., there is no significant difference in mean ART due to the flight path condition seen in the approach blunders with 30-deg deviation angle which occurred during the 1.0-s sensor update interval.

(2) 2.4-s sensor update interval, 30-deg deviation angle, calm vs turbulent flight path conditions:

Results indicate that t = -.37, P = .715 (df = 95). Since the probability is >.001, the null hypothesis is accepted, i.e., there is no significant difference in mean ART due to the flight path condition seen in the approach blunders with 30-deg deviation angle which occurred during the 2.4-s sensor update interval.

In summary, whether the sensor update interval was 1.0 s or 2.4 s, there was no significant difference in mean ART, and we find that there is no significant difference in mean ART attributed to flight path condition in the approach blunders with a 30-deg deviation angle.

Since it was found that the responses to approach blunders with a 15-deg deviation angle differed significantly by range (see Section 4.1.4), approach blunders with near and far range, 15-deg deviation angle, were analyzed separately to determine the effects of calm vs turbulent flight path. The values within this grouping are shown in Table 4-6.

Table 4-6

A Comparison of ART for "Single Type" Approach Blunders, 15-deg Deviation Angle, Near and Far Ranges, and Calm vs Turbulent Flight Path Conditions (3,400-ft Runway Separation)

Update Interval	1.0 s				2.4 s			
Deviation Angle	near		far		near		far	
Flight Path	calm	turb.	calm	turb.	calm	turb.	calm	turb.
# of Responses	49	49	50	50	49	49	49	49
Maximum ART	9.8	9.0	8.5	6.9	9.1	9.1	11.5	8.0
Minimum ART	-2.6	-2.0	0.5	0.4	-2.4	-2.0	0.2	1.0
sd	2.4	2.3	2.3	1.6	2.4	1.9	2.4	1.6
Mean ART	2.8	2.7	3.9	3.0	2.6	2.8	3.7	4.0

Four paired-sample t-tests were performed to assess the effect of flight path condition within ART to approach blunders with a 15-deg deviation angle, sorted by range.

(1) 1.0-s sensor update interval, 15-deg deviation angle, near range, calm vs turbulent flight path conditions:

Results indicate that $t = .43$, $P = .670$ ($df = 48$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to the flight path condition seen in the approach blunders with 15-deg deviation angle which occurred at near range during the 1.0-s sensor update interval.

(2) 1.0-s sensor update interval, 15-deg deviation angle, far range, calm vs turbulent flight path conditions:

Results indicate that $t = 2.98$, $P = .005$ ($df = 49$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to the flight path condition seen in the approach blunders with 15-deg deviation angle which occurred at the far range during the 1.0-s sensor update interval.

(3) 2.4-s sensor update interval, 15-deg deviation angle, near range, calm vs turbulent flight path conditions:

Results indicate that $t = -.47$, $P = .639$ ($df = 48$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to the flight path condition seen in the approach blunders with a 15-deg deviation angle which occurred at the near range during the 2.4-s sensor update interval.

(4) 2.4-s sensor update interval, 15-deg deviation angle, far range, calm vs turbulent flight path conditions:

Results indicate that $t = -1.18$, $P = .242$ ($df = 48$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to the flight path condition seen in the approach blunders of a 15-deg approach deviation angle which occurred at the far range during the 2.4-s sensor update interval.

In summary, when comparing calm vs turbulent conditions, 15-deg deviation angle, no significant difference in mean ART was found.

4.1.6 Effect of Approach Blunder Type

Various analyses were performed in order to assess the difference in ART which may have been attributed to the approach blunder type. Three blunder types were studied: "Single Type," "Distraction Type" (a Single Blunder preceded by a distraction), and a "Fast/Slow Type" approach blunder (see Section 2.1.1 for approach blunder definitions). The "Simultaneous Missed Approach Type" failed to develop useful information. Results from these approach blunders are, therefore, not included in the data analysis. This type of approach blunder involved a blunder after a dual missed approach. Since most scenarios ended with both aircraft landing or with one aircraft blundering and the other breaking out, controllers witnessing a dual missed approach – a rare event in actual operations – acted to resolve any possibility of a missed approach blunder by turning the aircraft away from each other even before a Caution Alert occurred. This phenomenon was found to occur in both live flights and simulations.

In this section, ART results on "Single Type" vs "Fast/Slow Type" approach blunders, 3,400-ft runway separation, are presented in Tables 4-7 through 4-10. ART results on "Single Type" vs "Distraction Type" approach blunders are presented in Tables 4-11 through 4-14. Following each table, results are presented regarding significant difference in mean ART to attributable approach blunder type.

Four paired-sample t-tests were performed in order to compare "Single Type" vs "Fast/Slow Type" approach blunders.

(1) 1.0-s sensor update interval, 15-deg deviation angle, near range, calm flight path condition, "Single Type" vs "Fast/Slow Type":

Table 4-7

A Comparison of ART for "Single Type" vs "Fast/Slow Type" Approach Blunders, 1.0-s Sensor Update Interval, 15-deg Deviation Angle, Near Range, Calm Flight Path Condition (3,400-ft Runway Separation)

Blunder Type	"Single"	"Fast/Slow"
# of Responses	49	49
Maximum ART	9.8	12.9
Minimum ART	-2.6	-1.7
sd	2.3	2.9
Mean ART	2.7	2.9

Results indicate that $t = -.52$, $P = .605$ ($df = 48$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to blunder type.

(2) 2.4-s sensor update interval, 15-deg deviation angle, near range, calm flight path condition, "Single Type" vs "Fast/Slow Type":

Table 4-8

A Comparison of ART for "Single Type" vs "Fast/Slow Type" Approach Blunders, 2.4-s Sensor Update Interval, 15-deg Deviation Angle, Near Range, Calm Flight Path Condition (3,400-ft Runway Separation)

Blunder Type	"Single"	"Fast/Slow"
# of Responses	47	47
Maximum ART	9.1	8.0
Minimum ART	-2.4	-2.6
sd	2.3	2.4
Mean ART	2.6	2.0

Results indicate that $t = 1.30$, $P = .201$ ($df = 46$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to blunder type.

(3) 1.0-s sensor update interval, 15-deg deviation angle, far range, calm flight path condition, "Single Type" vs "Fast/Slow Type":

Table 4-9

A Comparison of ART for "Single Type" vs "Fast/Slow Type" Approach Blunders, 1.0-s Sensor Update Interval, 15-deg Deviation Angle, Far Range, Calm Flight Path Condition (3,400-ft Runway Separation)

Blunder Type	"Single"	"Fast/Slow"
# of Responses	50	50
Maximum ART	8.5	16.3
Minimum ART	0.5	-0.6
sd	2.3	3.3
Mean ART	3.9	4.9

Results indicate that $t = -1.79$, $P = .079$ ($df = 49$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to blunder type.

(4) 2.4-s sensor update interval, 15-deg deviation angle, far range, calm flight path condition, "Single Type" vs "Fast/Slow Type":

Table 4-10

A Comparison of ART for "Single Type" vs "Fast/Slow Type" Approach Blunders, 2.4-s Sensor Update Interval, 15-deg Deviation Angle, Far Range, Calm Flight Path Condition (3,400-ft Runway Separation)

Blunder Type	"Single"	"Fast/Slow"
# of Responses	49	49
Maximum ART	11.5	8.2
Minimum ART	0.2	1.2
sd	2.4	1.6
Mean ART	3.7	3.8

Results indicate that t = -.34, P = .738 (df = 48). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to blunder type.

In summary, whether the approach blunder type was "Single Type" or "Fast/Slow Type," when comparing mean ART from approach blunders presented (holding constant the same sensor update interval, blunder angle, range, and flight path condition) there is no significant difference in the mean ART due to approach blunder type.

Four paired-sample t-tests were performed in order to compare "Single Type" vs "Distraction Type" approach blunders.

(1) 1.0-s sensor update interval, 15-deg deviation angle, far range, calm flight path condition, "Single Type" vs "Distraction Type":

Table 4-11

A Comparison of ART for "Single Type" vs "Distraction Type" Approach Blunders, 1.0-s Sensor Update Interval, 15-deg Deviation Angle, Far Range, Calm Flight Path Condition (3,400-ft Runway Separation)

Blunder Type	"Single"	"Distraction"
# of Responses	49	49
Maximum ART	8.5	10.0
Minimum ART	0.5	-2.8
sd	2.3	2.8
Mean ART	4.0	3.2

Results indicate that t = 1.85, P = .070 (df = 48). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to blunder type.

(2) 2.4-s sensor update interval, 15-deg deviation angle, far range, calm flight path condition, "Single Type" vs "Distraction Type":

Table 4-12

A Comparison of ART for "Single Type" vs "Distraction Type" Approach Blunders, 2.4-s Sensor Update Interval, 15-deg Deviation Angle, Far Range, Calm Flight Path Condition (3,400-ft Runway Separation)

Blunder Type	"Single"	"Distraction"
# of Responses	49	49
Maximum ART	11.5	7.5
Minimum ART	0.2	0.5
sd	2.4	1.6
Mean ART	3.7	2.8

Results indicate that $t = 3.07$, $P = .003$ ($df = 48$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to blunder type.

(3) 1.0-s sensor update interval, 30-deg deviation angle, far range, calm flight path condition, "Single Type" vs "Distraction Type":

Table 4-13

A Comparison of ART for "Single Type" vs "Distraction Type" Approach Blunders, 1.0-s Sensor Update Interval, 30-deg Deviation Angle, Far Range, Calm Flight Path Condition (3,400-ft Runway Separation)

Blunder Type	"Single"	"Distraction"
# of Responses	49	49
Maximum ART	6.8	7.0
Minimum ART	-1.9	-0.4
sd	1.5	1.5
Mean ART	2.4	2.8

Results indicate that $t = -1.81$, $P = .077$ ($df = 48$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to blunder type.

(4) 2.4-s sensor update interval, 30-deg deviation angle, far range, calm flight path condition, "Single Type" vs "Distraction Type":

Table 4-14

A Comparison of ART for "Single Type" vs "Distraction Type" Approach Blunders, 2.4-s Sensor Update Interval, 30-deg Deviation Angle, Far Range, Calm Flight Path Condition (3,400-ft Runway Separation)

Blunder Type	"Single"	"Distraction"
# of Responses	49	49
Maximum ART	7.4	7.2
Minimum ART	-1.8	-0.7
sd	1.4	1.3
Mean ART	2.4	2.4

Results indicate that $t = -.13$, $P = .895$ ($df = 48$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to blunder type.

In summary, when comparing "Distraction Type" vs "Single Type" approach blunders, no significant difference in mean ART was found. Although the difference in mean ART was not found statistically significant the reaction times indicated a general trend toward being similar or a bit faster in response to the "Distraction Type" vs "Single Type."

Originally, these distraction blunders were designed to assess whether distractions (deviations by the aircraft soon-to-be endangered) would cause controllers to divert attention from the soon-to-be blundering aircraft and result in a delayed response in breaking out the endangered aircraft. Instead, these scenarios sometimes had the opposite effect. These sudden and unexpected deviations apparently heightened controller awareness and resulted in faster breakouts of the endangered aircraft. It was determined that these distractions were quite artificial and not to be expected in normal operations. Therefore, as mentioned in Section 2.2.1 regarding Study II, the distractions were removed and those blunders were converted to "Single Type" approach blunders.

4.1.6.1 Effect of Sensor Update Interval on "Fast/Slow Type" Approach Blunders

The results for blunder type showed that in "Single Type" approach blunders, whether the sensor update interval was 1.0 s or 2.4 s, the ART remained basically the same. However, the results also showed that in "Fast/Slow Type" approach blunders presented at 1.0-s sensor update interval, the ART tended to be slower than the ART obtained in the 2.4-s sensor update interval blunders. The pertinent information from Tables 4-7 through 4-10 is summarized below in Table 4-15.

Table 4-15

Mean ART for "Fast/Slow Type" Approach Blunders, 15-deg Deviation Angle, Near and Far Range, Calm Flight Path Condition, Presented by Range and Sensor Update Interval (3,400-ft Runway Separation)

Sensor Update Interval	1.0 s	2.4 s
Near Range (Mean ART)	2.9	2.0
Far Range (Mean ART)	4.9	3.8

To assess the effect of sensor update interval in the "Fast/Slow Type" approach blunders, two paired-sample t-tests were performed, one for the approach blunders which occurred at near range and one for the approach blunders which occurred at far range.

(1) "Fast/Slow Type" approach blunder, 15-deg deviation angle, near range, calm flight path condition, 1.0-s vs 2.4-s sensor update interval:

Results indicate that $t = 2.30$, $P = .026$ ($df = 46$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to sensor update interval.

(2) "Fast/Slow Type" approach blunder, 15-deg deviation angle, far range, calm flight path condition, 1.0-s vs 2.4-s sensor update interval:

Results indicate that $t = 1.94$, $P = .058$ ($df = 49$). Since the probability is >.001, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to sensor update interval. However, it should be noted how close the probability came to reaching the level of significance, indicating a trend toward a significant difference due to sensor update interval.

In summary, there was no significant difference in the mean ARTs of "Fast/Slow Type" approach blunders that could be attributed to sensor update interval.

4.1.7 Effect of Controller Experience

The novice group, while radar qualified, had no Monitor Controller experience prior to the simulation. In the experienced group, the mean level of experience as a Monitor Controller was approximately 5 years. The range of experience was generally 2 to 5 years. However, three controllers had longer experience of 7, 11, and 12 years. In Table 4-16, it is seen that the means indicate that the experienced Monitor Controllers responded approximately 0.9 s later than the controllers who had no previous monitoring experience.

Table 4-16

A Comparison of Overall Alert Response Times of Experienced vs Novice Monitor Controllers

Monitor Controller Experience	Novice	Experienced
Number of Controllers	24	26
Number of Responses	572	614
Standard Deviation (s)	1.9	2.2
Mean (s)	2.4	3.3

A t-test for independent samples was performed in order to assess the difference in mean ART, novice vs experienced controller. Results indicate that $t = -7.07$, $P = .000$ (separate variance estimate procedure, $df = 1181.71$). This was a between-subject comparison, and the probability criteria set to indicate significant difference is .05. Since the probability is <.05, the null hypothesis is rejected; i.e., there is a significant difference in mean ART due to controller experience level.

In summary, this effect of controller experience level is very evident when examining Figure 4-2, which shows the mean ART for experienced vs novice controllers for each of 24 approach blunders. For all but one of the approach blunders, the experienced Monitor Controllers were slower than the novice Monitor Controllers. These phenomena occurred in response to simulations regardless of whether the sensor update interval was 1.0 s or 2.4 s.

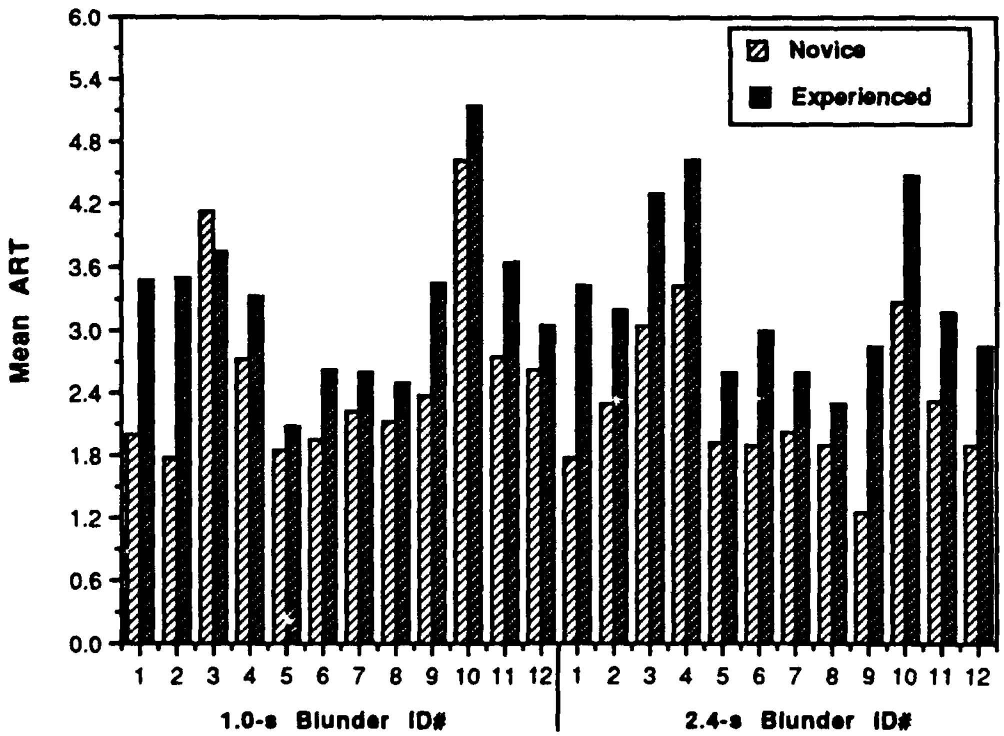

Figure 4-2. Mean ART of experienced vs novice Monitor Controllers for each approach blunder presented at 1.0-s and 2.4-s sensor update interval.

One might expect the experienced Monitor Controllers to have reacted more quickly. However, it may be that the more experience one has in a situation, the higher the awareness of the many things to consider. It also may be that with experience, the controller has the confidence to let the situation develop further before it is necessary to intervene. In addition, the novice group may have had more of a quick-trigger response of seeing and hearing the alert, and then reacting.

4.1.8 Another Measure of Effectiveness – The Rate of False Breakouts

The simulation presented opportunities for controllers to break out aircraft which were not scripted to be involved in a blunder. These opportunities were of two distinct types, the deliberate and inadvertent opportunities.

The deliberate opportunities included tracks deviating toward the NTZ at an angle of 5 to 20 deg, tracks gradually drifting off course toward the NTZ, and tracks which had drifted away from the NTZ, gradually coming back toward the localizer course and then overshooting it. The inadvertent opportunities arose from normal tracks, generated from the Memphis TNSE data during turbulent conditions. In these cases, a combination of radar noise and increased flight technical error created flight paths that activated the Caution Alert. The inadvertent opportunities more closely modeled the situation that might occur as a result of normal pilot technique. The deliberate opportunities represented more erratic piloting. The only difference between one of these and an approach blunder is whether the aircraft enters the NTZ before turning back to the approach course.

Table 4-17 presents the data on unnecessary/false breakouts. The results are categorized by sensor update interval and deliberate or inadvertent opportunity. It should be emphasized that the percentages shown are false breakouts as a percentage of breakout opportunities, not percentages of total flights, which would of course be significantly smaller.

These results were included in the Precision Runway Monitor Demonstration Report [5]. The data were derived from the responses of 20 of the 25 pairs of controllers. (Preliminary analysis of the remaining 5 pairs of controllers did not significantly change the findings. Further analysis was not warranted and, therefore, not performed.)

Table 4-17

False Breakouts
(3,400-ft Runway Separation)

Update Interval	1.0 s		2.4 s	
Type of Breakout Opportunity	Deliberate	Inadvertent	Deliberate	Inadvertent
Number of Pairs of Controllers	20	20	20	20
Total Nuisance Caution Alerts	160	1380	90	1170
Total False Breakouts	14	1	11	4
Percentage of False Breakouts	8.75%	<.1%	12%	<.4%
False Breakout Rate*	87	<1	120	<4

*per 1,000 False Breakout Opportunities

Table 4-17 shows that the false breakout rate was less when the faster sensor update interval was used. This was found for both types of breakout opportunities.

False breakouts occurred primarily from the so-called deliberate opportunities. Each of these involved aircraft approaching to within 100 or 200 ft of the NTZ, or deviating left and right off course several times. The aircraft would eventually return to course, but the controller had no way of anticipating this. By breaking out either the apparent blunderer or the adjacent aircraft, the controller acted on a judgment that NTZ penetration was imminent.

Examination of actual approach data collected at Memphis indicates that flight paths similar to the deliberate breakout opportunities are rare, occurring in less than 1% of the recorded approaches. Therefore, the false breakout rate per approach, of the highest number in the tables (12%), reduces to about 1 per 1,000.

The inadvertent opportunities were believed more typical of what would be expected to be an actual false breakout opportunity. The low inadvertent rate suggests that controllers are able to tolerate a high number of nuisance Caution Alerts in turbulent conditions. Because all aircraft evidence increased difficulties in tracking the localizer compared with calm wind conditions, controllers expected some deviations, and the occasional Caution Alerts did not prompt them to break aircraft out unnecessarily.

In summary, whether the sensor update interval was 1.0 s or 2.4 s, controllers had a low rate of false breakouts in response to simulations with typical flight path variations. In both the deliberate and inadvertent opportunities, the faster sensor update interval resulted in less false breakouts.

4.2 RESPONSES TO SIMULATIONS OF APPROACH BLUNDERS PRESENTED AT 4.8-S SENSOR UPDATE INTERVAL, 3,400-FT RUNWAY SEPARATION

4.2.1 Effect of 4.8-s Sensor Update Interval

In order to assess the effect of the 4.8-s sensor update interval when runway separation was 3,400 ft, the responses of the controllers to the "Single Type" approach blunders presented at that sensor update interval were studied. These data were collected during Weeks 1 through 12 of testing, i.e., involving 24 controllers. The data were collected to assess the benefit of the PRM system in the following hypothetical situation: the use of new displays and one-milliradian radar accuracy, 3,400 ft runway separation, without changing the sensor update interval from that of the production Mode S sensor, i.e., use of 4.8-s sensor update interval.

In Table 4-18, the ARTs' results are presented for the three sensor update intervals. These results are from the responses to the six "Single Type" approach blunders in common in all three sensor update interval conditions.

Table 4-18

A Comparison of ART for "Single Type" Approach Blunders Presented at Three Sensor Update Interval Conditions (3,400-ft Runway Separation)

Update Interval	1.0 s	2.4 s	4.8 s
# of Responses	121	120	121
Maximum ART	9.8	11.5	12.24
Minimum ART	-2.6	-2.6	-0.64
sd	2.3	2.3	2.3
Mean ART	3.3	3.4	4.2

Two paired-sample t-tests were performed to assess the effect of the slower sensor update interval of 4.8 s vs 1.0-s and 2.4-s sensor update intervals:

(1) 1.0-s vs 4.8-s sensor update interval:

Results indicate that $t = -3.45$, $P = .001$ ($df = 120$). Since the probability is .001, the null hypothesis is rejected; i.e., there is a significant difference in mean ART due to sensor update interval. This is a very strong effect. The probability of this effect occurring by chance due to sampling error is approximately 1 in 1,000.

(2) 2.4-s vs 4.8-s sensor update interval:

Results indicate that $t = -2.86$, $P = .005$ ($df = 119$). Since the probability is >.001 the null hypothesis is accepted, i.e., there is no significant difference in mean ART due to sensor update interval. However, although this probability value did not meet the stringent criteria set through application of the Bonferroni Adjustment, it indicates a strong trend toward significance.

In summary, results indicate approximately 1.0-s difference in mean ART in the 4.8-s sensor update condition vs the mean ART in the other two sensor update intervals. Controllers were 1.0 s slower in responding when the 4.8-s sensor update interval was used. So, despite the new displays and greater sensor accuracy, use of the 4.8-s sensor update interval resulted in delayed response times.

As a result of this finding, the decision was made to study the use of 4.8-s sensor update interval, with the new displays and greater sensor accuracy, but to change the runway separation to 4,300 ft. This testing was conducted during Weeks 13 through 25, i.e., involving 26 controllers and is discussed in Section 4.4.

Before moving on to those findings, we will consider the effect of deviation angle in approach blunders with 3,400-ft runway separation, 4.8-s sensor update interval. This was done in order to see if the findings would be similar to the findings regarding the other two sensor update intervals, i.e., that controllers responded approximately 1.0 s more rapidly to approach blunders with 30-deg vs 15-deg deviation angle (see Section 4.1.2).

4.2.2 Effect of Deviation Angle

In order to assess the effect of deviation angle in approach blunders with 3,400 ft runway separation, 4.8-s sensor update interval, "Single Type" approach blunders were studied. Table 4-19 presents the ARTs' results.

Table 4-19

A Comparison of ART for "Single Type" Approach Blunders, 4.8-s Sensor Update Interval, 15-deg vs 30-deg Deviation Angle (3,400-ft Runway Separation)

Deviation Angle	15 deg	30 deg
# of Responses	45	45
Maximum ART	9.6	8.0
Minimum ART	0.7	-0.6
sd	2.4	2.0
Mean ART	4.0	3.7

A paired-sample t-test was performed to assess the effect of deviation angle. Results indicate that $t = 0.6$, $P = .508$ ($df = 44$). Since the probability is >.001, the null hypothesis is accepted, i.e., there is no significant difference in mean ART due to deviation angle.

In summary, while controller response to approach blunders with 1.0-s and 2.4-s sensor update intervals showed a significant difference in mean ART attributable to deviation angle, this effect was not found in the 4.8-s sensor update interval condition.

This is probably due to the fact that whether a deviation is more or less severe, the controller decided he/she could not wait for an additional sensor update before making a breakout decision. Waiting another 4.8 s was not acceptable to the controllers.

4.3 EFFECT OF RUNWAY SEPARATION (3,400 FT VS 4,300 FT) ON RESPONSES TO SIMULATIONS OF APPROACH BLUNDERS PRESENTED AT 4.8-S SENSOR UPDATE INTERVAL

In order to assess the effect of the 4.8-s sensor update interval when runway separation was 3,400 ft vs 4,300 ft, the responses of the controllers to the "Single Type" approach blunders presented at that sensor update interval were studied. The data collected during Weeks 1 through 12 of testing with 3,400 ft runway separation were compared with the data collected during Weeks 13 through 25 of testing with 4,300 ft runway separation. This was done in order to assess the viability of using the PRM system while keeping the current standard of 4,300-ft runway separation.

In Table 4-20, the ARTs' results are presented for the "Single Type" approach blunders presented at 4.8-s sensor update interval, 3,400 vs 4,300 ft.

Table 4-20

A Comparison of ART for "Single Type" Approach Blunders Presented at 4.8-s Sensor Update Intervals (3,400-ft vs 4,300-ft Runway Separation)

Runway Separation	3,400 ft	4,300 ft
# of Responses	121	143
sd	2.3	3.1
Mean ART	4.2	1.6

A t-test for independent samples was performed to assess the significance of the difference between the two mean ARTs. (A paired-sample t-test, could not be used for this analysis. In this case, there was not a paired sample, i.e., the comparison of an individual's performance in one condition vs the same individual's performance in another condition. The comparison was made between one group of controllers who participated in the first half of the study and another group of controllers who participated in the second half of the study.)

Using a separate variance estimate, 2-tail probability, results indicate that $t = 8.58$, $P = .000$ ($df = 257.25$). This was a between-subject comparison and the probability criteria set to indicates significant difference is .05. Since the probability is <.05, the null hypothesis is rejected, i.e., there is a significant difference in mean ART due to runway separation. This is a very strong effect. The probability of this effect occurring by chance due to sampling error is less than 1 in 1,000.

Controller ART was significantly faster when the runway separation was increased from 3,400 ft to 4,300 ft. One possible explanation for the extreme difference in mean ART concerns the presence of a larger NOZ in the 4,300-ft runway separation condition. The controllers had the opportunity to observe the blundering aircraft for one or two more radar intervals prior to NTZ penetration. When the Caution Alert sounded, the aircraft was far from the centerline. There was little likelihood that this was a TNSE deviation and, therefore, the controller was confident in making the breakout decision and responded quickly.

This explanation is supported in the data on unnecessary breakouts. Table 4-21 presents data on unnecessary breakouts at the 4.8-s sensor update interval and compares 3,400-ft vs 4,300-ft runway separation. No nuisance Caution Alerts occurred at 4.8 s and 4,300 ft and, therefore, no unnecessary breakouts occurred, even for the deliberate opportunities ("deliberate" and "inadvertent" opportunities were defined in Section 4.1.8).

Table 4-21

Unnecessary Breakouts - Comparison of Runway Separations at 4.8-s Sensor Update Interval

Runway Separation	3,400 ft		4,300 ft	
Type of Breakout Opportunity	Deliberate	Inadvertent	Deliberate	Inadvertent
Number of Pairs of Controllers	14	14	12	12
Total Nuisance Caution Alerts	448	996	0	0
Total False Breakouts	5	17	0	0
Percentage of False Breakouts	1.1%	1.75%	0	0
False Breakout Rate*	11	17	0	0

*per 1,000 False Breakout Opportunities

Since with 4,300-ft runway separation, no nuisance Caution Alerts occurred, the controllers learned that when they did receive a Caution Alert it was probably an approach blunder in progress. It is, therefore, reasonable to expect that controllers would have greater confidence in making the breakout decisions and, therefore, they reacted more quickly when the runway separation was 4,300 ft.

4.4 RESPONSES TO SIMULATIONS OF APPROACH BLUNDERS PRESENTED AT 4.8-S SENSOR UPDATE INTERVAL, 4,300-FT RUNWAY SEPARATION

4.4.1 Effect of Deviation Angle

In order to assess the effect of deviation angle in approach blunders with 4,300-ft runway separation, 4.8-s sensor update interval, "Single Type" approach blunders were studied. Table 4-22 presents the ARTs results for the "Single Type" approach blunders in common in the 15-deg and 30-deg conditions.

Table 4-22

A Comparison of ART for "Single Type" Approach Blunders, 15-deg vs 30-deg Deviation Angle (4,300-ft Runway Separation)

Deviation Angle	15 deg	30 deg
# of Responses	47	47
Maximum ART	8.7	8.8
Minimum ART	-8.0	-4.2
sd	3.5	3.0
Mean ART	0.0	1.0

A paired-sample t-test was performed to assess the effect of deviation angle. Results indicate that $t = -1.58$, $P = .121$ ($df = 46$). Since the probability is >.001, the null hypothesis is accepted, i.e., there is no significant difference in mean ART due to deviation angle.

In summary, whether the deviation angle was 15 deg or 30 deg, mean ART did not differ significantly. The mean ART was 1.0 s or less. This means that, on average, controllers responded at the time of the Caution Alert or within 1.0 s after the Caution Alert. The difference between 0 and 1.0 s was not found to be statistically significant.

This quick response time is probably due to the controllers' high confidence in their breakout decisions. This increased confidence, seen in the case of 4,300-ft runway separation, was discussed in Section 4.3.

4.4.2 Effect of Approach Blunder Range

"Single Type" approach blunders were studied in order to assess the effect of the range at which the approach blunder occurred, 4.8-s sensor update interval, "Single Type" approach blunders were studied. Table 4-23 presents the ARTs results. Within the "Single Type" approach blunders, blunders were presented at both the near and far range, 30-deg deviation angle. In the 15-deg deviation angle condition, only near range deviations were included. Therefore, only results from the 30-deg deviation condition are presented below.

Table 4-23

A Comparison of ART for "Single Type" Approach Blunders, Near vs Far Deviation Range, 30-deg Deviation Angle (4,300-ft Runway Separation)

Deviation Range	Near	Far
# of Responses	22	22
Maximum ART	8.0	12.2
Minimum ART	-0.6	1.2
sd	2.0	2.2
Mean ART	3.1	5.7

A paired-sample t-test was performed to assess the effect of range in 30-deg deviation angle approach blunders. Results indicate that $t = -4.77$, $P = .000$ ($df = 21$). Since the probability is <.001, the null hypothesis is rejected, i.e., there is a significant difference in mean ART due to range. This is a very strong effect. The probability of this effect occurring by chance due to sampling error is less than 1 in 1,000.

In summary, whether an approach blunder was presented at 1.0-s or 2.4-s sensor update interval, when the deviation angle was 30 deg, the ART was significantly slower for approach blunders at far range than near range. Mean ART was approximately 2.6 s slower.

This finding of slower ART at far range is consistent with the findings reported in Section 4.1.4 regarding far range and 3,400-ft runway separation. As discussed in that section, it may be that, at the far range, the aircraft are not stable on the localizer and TNSE is greater. The controllers therefore use/allow more time to watch the aircraft before making a breakout decision.

4.4.3 Effect of Flight Path Condition

In order to assess the effect of flight path condition in approach blunders with 4,300-ft runway separation, 4.8-s sensor update interval, "Single Type" approach blunders, with 15-deg deviation angle, and occurring at near range were studied. Table 4-24 presents the ARTs results for the "Single Type" approach blunders in common in the calm and turbulent flight path conditions.

Table 4-24

A Comparison of ART for "Single Type" Approach Blunders, Calm vs Turbulent Flight Path Condition, 4.8-s Sensor Update Interval (4,300-ft Runway Separation)

Flight Path Condition	Calm	Turbulent
# of Responses	23	23
Maximum ART	5.0	8.7
Minimum ART	-5.0	-8.0
sd	3.5	3.6
Mean ART	0.0	0.0

A paired-sample t-test was performed to assess the effect of flight path condition. Results indicate that $t = 0.13$, $P = .895$ ($df = 22$). Since the probability is >.001, the null hypothesis is accepted, i.e., there is no significant difference in mean ART due to flight path condition.

4.4.4 Effect of Approach Blunder Type

In order to assess the effect of approach blunder type with 4,300 ft runway separation, 4.8-s sensor update interval, "Single Type" approach blunders were compared to "Fast/Slow Type" approach blunders. Table 4-25 presents the ARTs results for "Single Type" vs "Fast/Slow Type" approach blunders in common in both types of approach blunder type.

Table 4-25

A Comparison of ART for "Single Type" vs "Fast/Slow Type" Approach Blunders, 15-deg Deviation Angle, Near Range, Calm Flight Path Condition, 4.8-s Sensor Update Interval (4,300-ft Runway Separation)

Blunder Type	"Single"	"Fast/Slow"
# of Responses	24	24
Maximum ART	5.0	7.0
Minimum ART	-5.0	-4.8
sd	3.4	3.7
Mean ART	0.1	0.0

A paired-sample t-test was performed to assess the effect of "Single Type" vs "Fast/Slow Type" approach blunders. The analysis included ARTs to approach blunders with 15-deg deviation angle and near range, since a comparable data set was present in both the "Single Type" and "Fast/Slow Type" data category. Results indicate that $t = 0.16$, $P = .875$ ($df = 23$). Since the probability is >.001, the null hypothesis is accepted, i.e., there is no significant difference in mean ART due to approach blunder type, "Single Type" vs "Fast/Slow Type."

4.5 CONTROLLER OPINION ON THE USE OF THE PRM WHEN RUNWAY SEPARATION IS 3,400 FT

Controller survey forms were used to obtain the opinions of the controllers on the effectiveness of the PRM system and its overall acceptability for use. The controllers expressed overall approval with the PRM system. Controllers made some recommendations regarding personal preferences in the manner in which information was presented on the display.

Table 4-26 lists the percentage of controllers who agreed, disagreed, or were undecided regarding each survey statement. The complete text of each survey statement is also presented, accompanied by a summary of results and any narrative comments made by the controllers.

Table 4-26

Study I

Summary of Controller Survey Results

Survey Item	Agree (%)	Disagree (%)	Undecided (%)
2.0 GENERAL ACCEPTANCE			
2.1 Monitor final better than ARTS	100	0	0
2.2 High resolution color display better for monitor function than ARTS display	100	0	0
2.3 Automated alerts made it easier to detect and resolve blunders	100	0	0
2.4 Approaches with runways separated by 3,400/ 3,500 can be safely conducted	96	0	4
3.0 MONITOR CONTROLLER FUNCTIONS			
3.1 PRM is useful to prevent NTZ penetration	98	2	0
3.2 PRM is useful in resolving blunders	96	4	0
3.3 PRM is useful in detecting deviations	100	0	0
3.4 PRM is useful in monitoring the missed approach	88	6	6
4.0 NTZ ALERTS			
4.1 Yellow Caution Alert is useful	98	2	0
4.2 Voice alert is useful (Memphis only)	98	2	0
4.3 Red Warning Alert is useful	98	0	2
5.0 DISPLAY INFORMATION CONTENT & PRESENTATION			
5.1 Information on display is well placed and useful	98	0	2
5.2 Written information on display is easily read	96	4	0
5.3 Color is better than monochrome	100	0	0
5.4 deleted	n/a		
5.5 Parallel 200-ft lines are useful	92	2	6
5.6 Color selection of features is suitable	94	6	0
6.0 FEATURES			
6.1 History Trail	74	16	10
6.2 Projected Position Vector	94	0	6
7.0 TRAINING			
7.1 Training time was adequate	92	0	8
7.2 All information was provided	96	4	0
8.0 SIMULATION			
8.1 Simulated traffic density was realistic	98	2	0
8.2 Simulated blunder trajectories were realistic	54	40	6
8.3 Simulated missed approach trajectories were realistic	72	20	8
8.4 Audio portion of simulation was realistic	86	12	2

Survey Section 2: General Acceptance

Statement 2.1 PRM enabled me to monitor the final approach better than the existing Automated Radar Terminal System (ARTS) system.

Statement 2.2 PRM's high resolution color monitor is better for the monitor function than the current ARTS system.

Statement 2.3 The PRM display with the automated alerts made it easier to detect and resolve potential and actual blunders/deviations better than the existing ARTS system.

Fifty controllers unanimously agreed with the above three statements. Controllers made comments indicating a high level of acceptability of the system. The comments of many controllers were similar to this comment made by one controller, "The PRM system is very impressive, and the system should be implemented as soon as possible to airports that need to relieve congestion and controller workload and, most importantly, to enhance safety." When comparing the PRM system to the current ARTS system, controllers described PRM as being: "a vast improvement," commenting that there is "no comparison" and that "this system is much more accurate."

Controller comments on the automated alerts indicated unanimous approval. Comments indicated that the alerts are invaluable when considering ambient noise and distractions. One controller commented that the alerts are an "Excellent idea, considering the boredom factor at final monitor is very high, and your attention drifts." Another controller commented, "Visual and audible alarms are an absolute must for forewarning controllers."

Statement 2.4 Independent IFR approaches to runways separated by 3,400/3,500 ft can be safely conducted using the PRM.

Forty-eight controllers agreed with this statement. The two controllers who were undecided indicated that before making a decision, they would have liked more time in which to become familiar with the system.

Survey Section 3: Monitor Controller Functions

Statement 3.1 PRM is useful as a final approach monitor to prevent penetration of the NTZ.

Forty-nine controllers agreed with this statement. Many controllers stated that the combination of the faster sensor update interval and the presence of Warning Alerts greatly improved the safety of this type of operation. The one controller who disagreed stated, "Nothing will prevent penetration of the zone, if the aircraft angle of deflection is large leaving his final."

Statement 3.2 PRM is useful in resolving approach blunders once they have occurred.

Forty-eight controllers agreed with this statement. Comments from one controller who disagreed emphasized the need for new procedures to be developed for conducting simultaneous parallel approaches.

Statement 3.3 PRM is useful in detecting deviations from the designated approach course.

Fifty controllers unanimously agreed that PRM is useful in detecting deviations from the designated approach course. Controllers commented on the benefits of increased magnification. One controller's comment summarizes what many of the controllers expressed. He referred to the increased magnification, saying, "this makes small deviations more readily detectable."

Statement 3.4 PRM is useful in monitoring simultaneous missed approach to ensure that the required divergence is achieved.

Forty-four controllers agreed with this statement. Based on the comments from controllers who either disagreed or were undecided, they were not saying that PRM is not useful in monitoring the missed approach. They commented that monitoring the missed approach should be the responsibility of the local controller and not the Monitor Controller.

Survey Section 4: NTZ Alerts

Statement 4.1 The Yellow/Caution Visual Alert, predicting "x" seconds or less until NTZ penetration, is useful.

Forty-nine controllers agreed with this statement. The one controller who disagreed about its usefulness reported having difficulty seeing the yellow color of a particular aircraft ID when he was not looking directly at it. No other controller reported having this difficulty.

Statement 4.2 The Voice Alert accompanying the Yellow/Caution Visual Alert is useful.

All but one controller agreed that the voice alert was useful. The one controller who disagreed reported preferring a "beep" which would be heard externally from the headset audio.

Statement 4.3 The Red/Warning Visual Alert, indicating that NTZ penetration has occurred, is useful.

Forty-nine controllers agreed with this statement. One controller who agreed commented that the Warning Visual Alert eliminates questions regarding whether or not penetration of the NTZ has occurred.

Survey Section 5: Display Information Content and Presentation

Statement 5.1 The information presented in the PRM display is well-placed and easily visible.

Forty-nine controllers agreed with this statement. The one controller who was undecided stated that he needed more time with the system before making a judgment.

Statement 5.2 The written information presented in the PRM display is easily read.

Forty-eight controllers agreed with this statement. Two controllers who disagreed stated that the menu was "cluttered." Their disagreement referred to the menu and not the readability of the display text. The menu structure was not under study in this experiment. The current menu structure is lengthy, since it includes items which are used by the experimenter in setting up the simulation. The actual menu that will be seen by a Monitor Controller will be greatly streamlined.

Statement 5.3 The color display is more effective than a monochrome display.

Fifty controllers unanimously agreed with this statement.

Statement 5.4 deleted

Statement 5.5 The parallel 200-ft lines are a useful aid in detecting deviations from the approach course and in predicting the potential for an NTZ penetration.

Forty-six controllers agreed that the lines are useful. One controller disagreed and three were undecided. The majority of controllers stated that the lines help to detect deviations at the earliest time. Of the controllers who were undecided or disagreed, one stated that he/she did not use the lines and found them to be "unnecessary clutter." One controller suggested increasing the distance between lines, thereby reducing the number of lines. Some controllers stated that the lines should be optional, and expressed that some controllers would benefit from their use and some would not.

Statement 5.6 The color selection for the features on the display is suitable.

Forty-seven controllers agreed with this statement. Three controllers disagreed. One controller commented that the predictor lines should be a color which would "stand out" more. Another controller commented that the "Caution yellow should be brighter." This was the same controller, discussed above (Statement 4.1), who had difficulty seeing the yellow color of a particular aircraft ID when he was not looking directly at it. No other controller reported having any difficulty seeing the yellow color. This one controller's difficulty perceiving the yellow color illustrates the value of having redundancy in the alert system. In addition to visual, color-coded alerts, there are accompanying audible alerts.

Survey Section 6: Features

Statement 6.1 The History Trail is useful in assisting you to perform the Monitor Controller task.

Thirty-seven controllers agreed that it is useful. Of the controllers who disagreed or were undecided, many stated that the use of this feature should be a matter of personal preference.

Statement 6.2 The projected Position Vector is useful in assisting you to perform the Monitor Controller task.

Forty-seven controllers agreed that it is useful. Many controllers stated that this feature is one of the best aspects of the system. One controller commented, "I would like this to change color if the projected turn is more than 10 deg."

Survey Section 7: Training

Statement 7.1 Adequate training time was provided to become familiar with the display before testing began.

Forty-six controllers agreed with this statement. Two of the four controllers, who were undecided stated that they would have liked a little more time working with the display before testing began.

Statement 7.2 All information needed, to aid me in performing the monitoring task, was provided.

Forty-eight controllers agreed with this statement. Overall, controllers commented that the training was "excellent" and that "there was always someone there if a question or concern arose." One controller who disagreed said that the ability to change intensities was not fully explained.

Survey Section 8: The Simulation

Statement 8.1 The simulated traffic density was realistic.

Forty-nine controllers agreed with this statement. The controller who disagreed commented that there should have been "more bumps into the NTZ."

Statement 8.2 The simulated aircraft "blunder" trajectories were realistic.

Controller opinion was split on this item. Most controllers who disagreed gave one of the following reasons:

1) Some controllers found it difficult to adjust to the magnification of the x- and y-axis. The magnification makes the angle of the deviation appear more severe than it actually is. Some controllers commented that the angle of deviation was too great and, therefore, unrealistic. In the simulation, the angle of the deviations did not exceed 30 deg, but some controllers said that it was greater.

2) Some controllers said that there were too many emergencies and that this was unrealistic. The simulation did intentionally show many more blunders than one would experience in actual operations. Actual blunders are infrequent and, therefore, difficult to study. Through simulation a number and variety of blunders were presented in order to obtain valuable data on controller responses.

Statement 8.3 The simulated aircraft missed approach trajectories were realistic.

The majority of controllers agreed with this statement. Many controllers who disagreed stated that the scenarios which depicted two aircraft on adjacent approach paths, making a simultaneous missed approach, and then simultaneously blundering toward the NTZ, i.e., toward each other, was highly unlikely. Some controllers commented that, since the probability of this event is so small, this event should not have been included in the scenarios.

Statement 8.4 The audio portion of the simulation was realistic.

The majority of controllers agreed with this statement. For the recorded audio, one controller and one pilot spoke the parts of all pilots and all local controllers. One controller who disagreed commented that the voices were too monotonous. A few controllers commented that the background audio was "too wordy."

Survey Section 9: Comments

Controllers were asked to comment on any changes to the simulation which might enhance its realism. Controllers suggested simulating the actual work environment that they experience. They sited the presence of many more distractions in a live TRACON. Controllers commented that more

speed changes should be included in the simulation. Approximately three speed changes per hour were scripted into the Memphis simulation.

Controllers were asked to identify any factors in the simulation which might have affected the quality of the reaction time measurement. Some controllers commented that there were many more blunders than one would encounter during actual monitoring. One controller commented that this created stress and may have slowed his responses. Another controller commented that this heightened his anticipation and may have quickened his responses.

Controllers were asked to make any additional comments regarding the simulation, the display, or the study procedures. Many positive comments were received. Controllers reported being impressed with the system and generally stated that it should be implemented as soon as possible.

Some concerns were voiced by controllers. The controllers preferred the 1.0-s and 2.4-s sensor update intervals to the 4.8-s sensor update interval. The 4.8-s sensor update interval was said to be "too slow." There was also concern that problems may be encountered with frequency congestion, especially when the 4.8-s sensor update interval is used. A few controllers were concerned that the controller's communication transmission may be blocked at a critical time by an aircraft transmitting on the frequency. There were also concerns that in using the 4.8-s sensor update interval, many unnecessary corrective headings may have to be issued.

5. RESULTS OF STUDY II

In Section 5, the results of Study II are discussed. This section focuses on controller response to simulations presented at 1.0-s and 2.4-s sensor update intervals, 3,000-ft runway separation. Where applicable, results of Study I (3,400-ft runway separation) are compared to results of Study II.

Throughout Section 5, there is a brief description of each analysis performed. ART results which are statistically significant are underlined. Throughout Section 5 within-subject comparisons are made and the probability criteria set for interpreting a significant difference between means is .005 or less (computation of probability criteria is discussed in Section 3.3.1.) Results of the Controller Opinion Survey used for Study II are presented in Section 5.5.

Before delving into the details of each analysis area, an "Overview of Findings" is presented. This gives the reader a quick look at the answers to the research questions asked in Study II and listed in Section 2.2.2. In addition, reference is made to the section in which greater detail on findings can be found.

Overview of Findings	
Question 1:	How does sensor update interval affect reaction time?
Findings:	Whether the sensor update interval was 1.0 s or 2.4 s, the ART did not differ significantly. Mean ART for both sensor update intervals was approximately 2.5 s. (For details, see Section 5.1.)
Question 2:	Are there differences in reaction time attributable to runway separation, specifically, 3,000 ft vs 3,400 ft?
Findings:	Whether the runway separation was 3,000 ft or 3,400 ft, mean ART did not differ significantly. However, an area of difference and concern is the effect of total navigational system error (TNSE) in the 3,000-ft runway separation condition. (For details, see Section 5.2.)
Question 3:	When the runway separation is 3,000 ft, are there differences in reaction time attributable to: a. the angle of the deviation of the approach blunder, b. the range (nmi from the runway threshold) of aircraft at time of blunder, and c. the type of blunder, specifically, "Single Type" vs "Fast/Slow Type?"
Findings:	a. No, no significant difference was found to be attributable to deviation angle. (For details, see Section 5.2.) b. Yes, when comparing approach blunders occurring at far range vs near range, 15-deg deviation angle. Whether an approach blunder was presented at 1.0-s or 2.4-s sensor update interval, the mean ART was significantly slower for blunders at far range than at near range. Mean ART for far range blunders was 1.7 s slower in the 1.0-s sensor update interval condition and 2.4 s slower in the 2.4-s sensor update interval. (For details, see Section 5.3.) c. No, no significant difference was found to be attributable to blunder type in the case of "Single Type" vs "Fast/Slow Type." (For details, see Section 5.4.)
Question 4:	Will controllers accept the PRM system as a means of safely conducting independent parallel approaches during IFR conditions to parallel runways spaced 3,000 ft apart ?
Findings:	Half of the controllers agreed that independent IFR approaches to runways separated by 3,000 ft can be safely conducted using the PRM. However, half of the controllers were undecided. In general, controllers voiced concerns regarding the increased workload and possible frequency congestions that may be caused by the effect of TNSE experienced at this runway separation. (For details see Section 5.5.)

5.1 EFFECT OF RUNWAY SEPARATIONS AT BOTH SENSOR UPDATE INTERVALS

In order to assess the effect of runway separation, the ART results from Study I, "Single Type" approach blunders, 3,400-ft runway separation, were compared to the ART results from Study II, "Single Type" approach blunders, 3,000-ft runway separation. The results from both sensor update intervals are presented in Table 5-1.

The reader is cautioned that there are limits to the comparisons that can be made between these two sets of data. The two studies were not the same in all aspects expect for one variable, i.e., runway separation. Differences between the arrival push simulations used in each of the studies were discussed in Section 2.2. One of the main differences was the increase in TNSE depicted in the simulations used in Study II. In addition, Study I results are based on the responses of 50 controllers, while Study II was a small sample study involving the responses of 10 controllers. Since Study II results are based on a small sample size, findings are suggestive rather than definitive.

The intention of Study II was to serve as a starting point in studying the problem of reduced separation in the case of runway separation of 3,000 ft. It was hoped that this small-sample study would determine the feasibility of this type of operation and might identify issues and procedures that should be resolved prior to implementation. With the limitations and intention of Study II in mind, we proceed to the findings.

Table 5-1

A Comparison of ART for "Single Type" Approach Blunders at Two Sensor Update Intervals and Two Runway Separations

Runway Separation	3,400 ft		3,000 ft	
Update Interval	1.0 s	2.4 s	1.0 s	2.4 s
# of Responses	392	392	60	48
Maximum ART	16.3	11.5	6.9	7.5
Minimum ART	-2.8	-2.7	0.7	-0.7
sd	1.9	1.9	1.2	1.6
Mean ART	2.7	2.8	2.5	2.6

The above mean ARTs indicate that whether the runway separation was 3,400 ft or 3,000 ft and whether the sensor update interval was 1.0-s or 2.4-s, controller reaction time remained basically the same. Therefore, when we investigate differences between results obtained in response to 3,000 ft vs 3,400 ft, ART does not appear to be an area of significant difference. The area of greatest difference appears to be the effect of TNSE in the 3,000-ft runway separation condition. Due to the decreased size of the NOZ, TNSE caused a number of aircraft to near or enter the NTZ. As a result, two types of nuisance alerts occurred: 1) Caution Alerts on aircraft that then return to course and do not penetrate the NTZ, and 2) Warning Alerts on aircraft that skirt the NTZ, penetrate it briefly thus setting off an alert, but then return to course. Figure 5-1 depicts the two types of nuisance alerts.

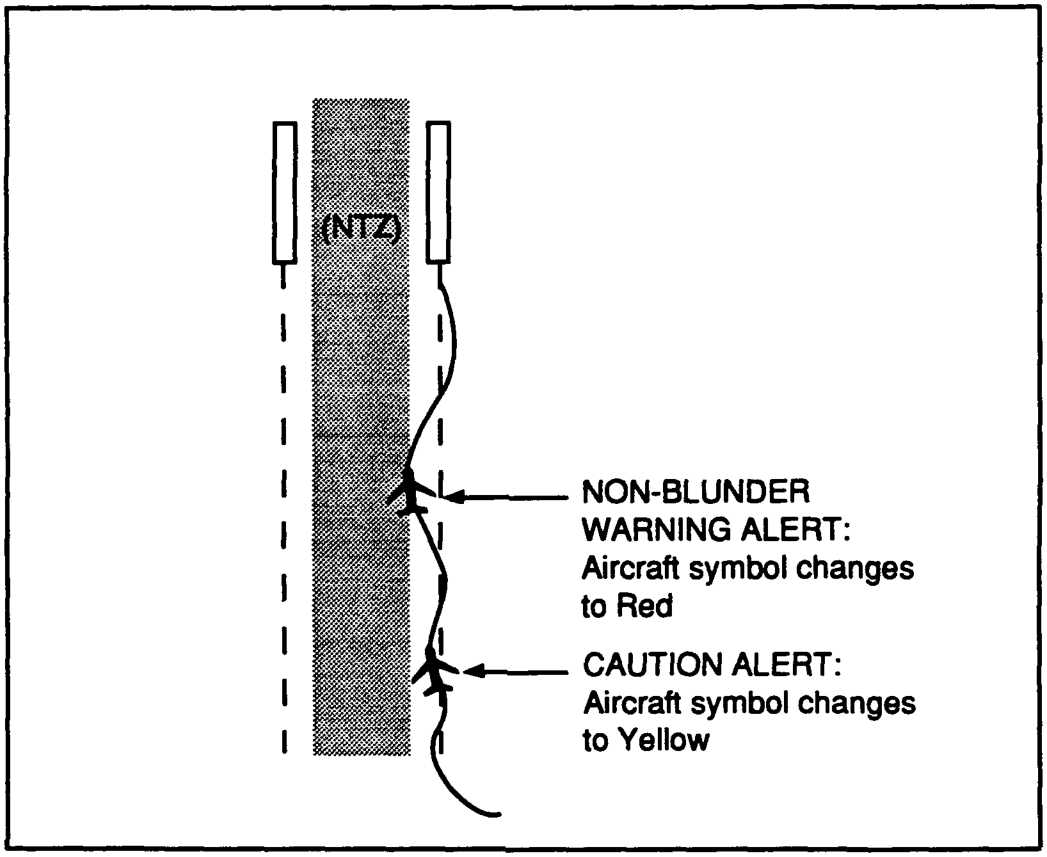

Figure 5-1. PRM Nuisance Alerts when the runway separation is 3,000 ft.

These deviations and the resulting nuisance alerts, can result in an increase in controller workload. They may cause the controller to issue numerous instructions to the pilot to return to course, and they may cause the controller to break out what appears to be (but is not) an endangered aircraft. If controller workload is increased, one would expect that the length of time the controller should serve on the Monitor Controller position should be decreased.

In addition, pilot workload becomes a concern. If a pilot is given a go-around due to a non-blunder Warning Alert, this increases the workload of the aircrew. There is also a monetary cost for the additional time and fuel used. Nuisance alerts also have an effect on communication load. With an increase in the number of communication transmissions, frequency congestion may result.

Table 5-2 lists the number of non-blunder Warning Alerts and the breakouts which followed the occurrence of these alerts.

Table 5-2

Non-Blunder Warning Alerts and Subsequent Breakouts (3,000-ft Runway Separation)

# of Pairs of Controllers	5
Total # of Aircraft	3160
Total # of Non-Blunder Warning Alerts	69
# of Non-Blunder Warning Alerts which resulted in breakouts	21

In summary, one of the main results of Study II is the realization that options for decreasing the effect of TNSE needs to be explored. By decreasing the number of deviations described, there should be a subsequent decrease in both workload of controllers and aircrews and also cost, time, and overall safety benefits would result.

5.2 EFFECT OF DEVIATION ANGLE AT BOTH SENSOR UPDATE INTERVALS

In order to assess the effect of deviation angle, the responses of the controllers to the "Single Type" approach blunders were analyzed. ART results are presented in Table 5-3.

Table 5-3

A Comparison of ART for "Single Type" Approach Blunders for Both Sensor Update Intervals and Both Deviation Angles (3,000-ft Runway Separation)

Runway Separation	3,000 ft			
Update Interval	1.0 s		2.4 s	
Deviation Angle (deg)	15	30	15	30
# of Responses	20	28	20	28
Maximum ART	3.3	6.9	7.6	4.8
Minimum ART	0.7	1.0	0.2	0.7
sd	0.7	1.4	2.0	1.2
Mean ART	2.0	2.4	3.2	2.2

As discussed in Section 4.1.3, results of Study I indicate that at both sensor update intervals, with runway separation of 3,400 ft, the mean ART for approach blunders with 30-deg deviation angle was approximately 1.0 s faster than for approach blunders with 15-deg deviation angle (approximately 2.2-2.3 s vs 3.1-3.3 s). This difference in mean ART was found to be significant. With a 30-deg deviation angle, penetration of the NTZ occurred more rapidly than with a 15-deg deviation angle. Therefore, there was less time before NTZ penetration, so the controller reacted more rapidly to the 30-deg blunders. This result was not found in the case of 3,000-ft runway separation.

A paired-sample t-test was performed in order to assess the statistical significance of the difference between the mean ARTs for approach blunders presented at 1.0-s sensor update interval, 15-deg vs 30-deg deviation angles, 3,000-ft runway separation. Results indicate that $t = .22$, $P = .828$ ($df = 29$). Since the probability is >.005, the null hypothesis is accepted, i.e., there is no significant difference in mean ART due to deviation angle.

A paired-sample t-test was performed in order to assess the statistical significance of the difference between the mean ART for approach blunders presented at 2.4-s sensor update interval, 15-deg vs 30-deg deviation angles, 3,000-ft runway separation. Results indicate that $t = 2.18$, $P = .044$ ($df = 17$). Since the probability is >.005, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to blunder angle.

In summary, while deviation angle was a key factor in mean ART when runway separation was 3,400 ft, it did not result in significant differences in mean ART when the runway separation was 3,000 ft. This may be caused by the lessened NOZ in the 3,000-ft situation.

5.3 EFFECT OF APPROACH BLUNDER RANGE

The effect of the range at which the approach blunder occurred was studied within approach blunders presented at the two sensor update intervals and two deviation angles. ART results are presented in Table 5-4 for approach blunders with a 15-deg and a 30-deg deviation angle when the range of the approach blunder was near vs far from the runway threshold. ART for both 1.0-s and 2.4-s sensor update intervals in the "Single Type" of approach blunder are shown.

Table 5-4

A Comparison of ART for "Single Type" Approach Blunders, 15-deg vs 30-deg Deviation Angle, and Near vs Far Ranges (3,000-ft Runway Separation)

Update Interval	1.0 s				2.4 s			
Deviation Angle (deg)	15		30		15		30	
Blunder Range	near	far	near	far	near	far	near	far
# of Responses	10	10	10	10	10	10	8	8
Maximum ART	3.3	5.8	6.8	2.6	4.7	7.6	4.5	3.0
Minimum ART	0.8	2.2	1.0	1.3	0.2	2.4	0.2	0.7
sd	0.7	1.2	2.0	0.4	1.3	1.9	1.4	1.2
Mean ART	1.9	3.6	3.2	1.7	2.0	4.4	2.1	2.0

Four paired-sample t-tests were performed to assess the effect of range on the ART to approach blunders within a 15-deg and a 30-deg deviation angle.

(1) 1.0-s sensor update interval, 15-deg deviation angle, near vs far range:

Results indicate that $t = -4.27$, $P = .002$ ($df = 9$). Since the probability is <.005, the null hypothesis is rejected; i.e., there is a significant difference in mean ART due to the range at which the approach blunder with a 15-deg deviation angle occurred during the 1.0-s sensor update interval. This is a very strong effect. The probability of this effect occurring by chance due to sampling error is approximately 2 in 1,000. In the far range approach blunders, the mean ART was 1.7 s longer than during the near range approach blunders.

(2) 1.0-s sensor update interval, 30-deg deviation angle, near vs far range:

Results indicate that $t = 2.19$, $P = .056$ ($df = 9$). Since the probability is >.005, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to the range at which the approach blunder with a 30-deg deviation angle occurred during the 1.0-s sensor update interval.

(3) 2.4-s sensor update interval, 15-deg deviation angle, near vs far range:

Results indicate that $t = -4.16$, $P = .002$ ($df = 9$). Since the probability is <.005 the null hypothesis is rejected; i.e., there is a significant difference in mean ART due to the range at which the approach blunder with 15-deg deviation angle occurred during the 2.4-s sensor update interval. This is a very strong effect. The probability of this effect occurring by chance due to sampling error is approximately 2 in 1,000. This result is similar to the results found for the same deviation angle and range in the 1.0-s sensor update interval condition.

(4) 2.4-s sensor update interval, 30 deg deviation angle, near vs far range:

Results indicate that $t = 0.12$, $P = .905$ ($df = 7$). Since the probability is >.005, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to the range at which the approach blunders with a 30-deg deviation angle occurred during the 2.4-s sensor update interval.

In summary, whether an approach blunder was presented at 1.0-s or 2.4-s sensor update interval, when the deviation angle was 15 deg the ART was significantly slower for blunders at far ranges than the ART was for approach blunders at near ranges. Mean ART was approximately 1.7 s slower in the 1.0-s sensor update interval condition and approximately 2.4 s slower in the 2.4-s sensor update interval condition.

The reader is cautioned that in the above four paired-sample t-tests, the number of responses was quite small. Data were derived from a small sample of controllers (8 to 10 controllers) each responding to one approach blunder of the specific type analyzed. However, it is interesting to find the similarity in findings from Study I and Study II. Controllers reacted more slowly to the 15-deg deviation angle approach blunders at far range than to those at near range. This effect was the same regardless of whether the approach blunder was presented at 1.0-s or 2.4-s sensor update interval.

The rationale for this result (stated in Section 4.1.4) that was given in the case of Study I (3,400-ft runway separation) holds true in the case of Study II (3,000-ft runway separation). It may be that this effect occurred in the approach blunders with 15-deg deviation angle and not in the

30-deg deviation angle, because with the more severe deviation angle of 30 deg, the controllers know that they must act as quickly as possible regardless of the range of the blunder. A question is: Why on the 15-deg approach blunders would ART be slower when the approach blunder occurs further from the runway threshold? It may be because at the far range the aircraft are not stable on the localizer, TNSE is greater, and more Caution Alerts are occurring. The controllers may have been waiting for greater flight path stabilization and, therefore, waited longer after the Caution Alert was received at the far range vs near range.

5.4 EFFECT OF APPROACH BLUNDER TYPE

In order to assess the difference in ART which may have been attributed to the approach blunder type, two approach blunder types were studied: "Single Type" and "Fast/Slow Type" approach blunder (see Section 2.1.1 for approach blunder definitions). Tables 5-5 through 5-8 provide summaries of ART results on these two types of approach blunders. Four paired-sample t-tests were performed in order to compare these two approach blunder types and results are provided after each table.

(1) 1.0-s sensor update interval, 15-deg deviation angle, near range:

Table 5-5

A Comparison of ART for "Single Type" vs "Fast/Slow Type" Approach Blunders, 1.0-s Sensor Update Interval, 15-deg Deviation Angle, Near Range (3,000-ft Runway Separation)

Blunder Type	"Single"	"Fast/Slow"
# of Responses	10	10
Maximum ART	3.3	7.1
Minimum ART	0.8	0.8
sd	0.7	1.8
Mean ART	1.9	2.9

Results indicate that $t = -2.59$, $P = .029$ ($df = 9$). Since the probability is >.005, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to blunder type. (See Section 4.1.5).

(2) 2.4-s sensor update interval, 15-deg deviation angle, near range:

Table 5-6

A Comparison of ART for "Single Type" vs "Fast/Slow Type" Approach Blunders, 2.4-s Sensor Update Interval, 15-deg Deviation Angle, Near Range (3,000-ft Runway Separation)

Blunder Type	"Single"	"Fast/Slow"
# of Responses	10	10
Maximum ART	5.8	7.9
Minimum ART	2.2	3.0
sd	1.2	1.4
Mean ART	3.6	4.2

Results indicate that $t = -0.98$, $P = .355$ ($df = 9$). Since the probability is >.005, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to approach blunder type.

(3) 1.0-s sensor update interval, 15-deg deviation angle, far range:

Table 5-7

A Comparison of ART for "Single Type" vs "Fast/Slow Type" Approach Blunders, 1.0-s Sensor Update Interval, 15-deg Deviation Angle, Far Range (3,000-ft Runway Separation)

Blunder Type	"Single"	"Fast/Slow"
# of Responses	9	9
Maximum ART	4.7	3.5
Minimum ART	0.2	0.7
sd	1.3	1.1
Mean ART	2.2	2.1

Results indicate that $t = -.09$, $P = .927$ ($df = 8$). Since the probability is >.005, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to approach blunder type.

(4) 2.4-s sensor update interval, 15-deg deviation angle, far range:

Table 5-8

A Comparison of ART for "Single Type" vs "Fast/Slow Type" Approach Blunders, 2.4-s Sensor Update Interval, 15-deg Deviation Angle, Far Range (3,000-ft Runway Separation)

Blunder Type	"Single"	"Fast/Slow"
# of Responses	9	9
Maximum ART	7.6	6.3
Minimum ART	2.4	1.6
sd	1.9	1.3
Mean ART	4.4	3.0

Results indicate that $t = 1.73$, $P = .118$ ($df = 9$). Since the probability is >.005, the null hypothesis is accepted; i.e., there is no significant difference in mean ART due to approach blunder type.

Whether the approach blunder type was "Single Type" or "Fast/Slow Type," when comparing ART from blunders presented at the same sensor update interval, deviation angle, and range, there is no significant difference in the ART due to approach blunder type.

5.5 CONTROLLER OPINION ON THE USE OF THE PRM WHEN RUNWAY SEPARATION IS 3,000 FT

Controller opinion survey forms were used to obtain the opinions of the controllers on the effectiveness of the PRM system and its overall acceptability for use. Table 5-9 lists the percentage of controllers who agreed, disagreed, or were undecided regarding each survey statement. The complete text of each survey statement is also presented, accompanied by a summary of results and any narrative comments made by the controllers.

Table 5-9

Study II
Summary of Controller Opinion Survey Results

Survey Item	Agree (%)	Disagree (%)	Undecided (%)
2.0 **GENERAL ACCEPTANCE**			
2.1 Approaches with runways separated by 3,000 ft can be safely conducted	50	0	50
3.0 **TRAINING**			
3.1 Training time was adequate	100	0	0
3.2 All information was provided	100	0	0
4.0 **SIMULATION**			
4.1 Simulated traffic density was realistic	90	10	0
4.2 Simulated blunder trajectories were realistic	60	20	20
4.3 Audio portion of simulation was realistic	70	20	10

Survey Section 2: General Acceptance

Statement 2.1 Independent IFR approaches to runways separated by 3,000 ft can be safely conducted using the PRM.

Half of the controllers agreed with this statement and half were undecided. Many of the controllers stated that operations can or might be safely conducted with 1.0-s sensor update interval. Their opinion was divided on the use of 2.4-s sensor update interval. They were concerns that with the decreased runway separation (decreased from 3,400 to 3,000 ft), the faster update interval might be necessary.

There were also concerns that with the decreased runway separation, i.e., decreased NOZ, the effect of TNSE is exacerbated and might result in more unnecessary breakouts. Some controllers also voiced concern regarding the amount of time on the position. This is discussed further under "Additional Comments" made by the controllers.

Survey Section 3: Training

Statement 3.1 Adequate training time was provided to become familiar with the display before beginning the testing.

All controllers agreed with this statement. As the reader will recall, these subjects also participated in Study I and were, therefore, familiar with the PRM system.

Statement 3.2 All information needed to aid me in performing the monitoring task was provided.

All controllers agreed with this statement.

Survey Section 4: The Simulation

Statement 4.1 The simulated traffic density was realistic.

Nine out of the ten controllers agreed with this statement. The controller who disagreed commented that the density was sufficient as far as the number of aircraft involved on the final approach, but that more transmissions were needed to be mixed into the audio.

Statement 4.2 The simulated aircraft "blunder" trajectories were realistic.

Six controllers agreed, two disagree, and two were undecided. Similar to the responses given in Study I to this question, most controllers who disagreed or were undecided gave one of the following reasons: 1) Some controllers said that it was difficult to adjust to the magnification of the x and y axis. The magnification makes the angle of the deviation appear more severe than it actually is. 2) Some controllers said that there were too many emergencies and that this was unrealistic. The simulation did intentionally show many more blunders than one would experience in actual operations. Actual blunders are infrequent and, therefore, difficult to study. Through simulation, a number and variety of blunders were presented in order to obtain valuable data on controller responses.

Statement 4.3 The audio portion of the simulation was realistic.

Seven controllers agreed, two disagreed, and one was undecided. Two controllers said that there needed to be added communications. One controller mentioned that it was monotonous hearing the same two pre-recorded voices throughout the study.

Survey Section 5: Additional Comments

Controllers were asked to comment on any changes to the simulation which might enhance its realism. Controllers suggested that more speed changes and additional traffic might be included in the simulation. One controller mentioned that the simulations used in this study did not include turbulent flight path conditions, which had been included in Study I. Two controllers recommended further testing with wind to consider its effect with the reduced runway separation.

Controllers were asked to identify any factors in the simulation which might have affected the quality of the reaction time measurement. One controller recommended that the scope be tilted for easier scanning. Several controllers mentioned that the length of time on position may have affected their response time. Each simulated monitoring session was about 45 to 75 minutes in length. Some controllers recommend the time on position should be no more than 60 minutes, and perhaps less. One controller mentioned that in Atlanta they are required to write down all aircraft IDs in case of an equipment failure and, so they would have that information. This requires attention to be diverted away from the radar screen. This was not required during the study. If this requirement is present during implementation of this new equipment in the field, this added task should be considered in assessing controller response time.

Controllers were asked to make any additional comments regarding the simulation, the display, or the study procedures. Some concerns were voiced by controllers. The greatest concern seemed to be workload and time on position. With the decreased NOZ controllers found that they had to increase their attention to every possible deviation. There was also concern that the faster update interval of 1.0 s would be necessary vs the 2.4-s sensor update interval. Controllers feared making too many unnecessary break-outs with the slower update interval in use. The need for training and new procedures was mentioned as being necessary, if decreased separation is to be accepted.

6. CONCLUSIONS AND RECOMMENDATIONS

Conclusions on Alert Response Time (ART) derived from Study I are discussed in Section 6.1. Conclusions on ART derived from Study II are discussed in Section 6.2. Controller opinion on use of the PRM is discussed in Section 6.3. Recommendations for future research are included in Section 6.4.

6.1 STUDY I

6.1.1 Conclusions on 1.0-s and 2.4-s Sensor Update Interval, 3,400-ft Runway Separation

Table 6-1 provides a quick reference of the results of the comparisons performed. An asterisk indicates probability values which showed a significant difference in mean ART. Reference is made to the section in which the analysis is discussed in detail.

Table 6-1

Comparisons Performed In Study I

1.0-s and 2.4-s Sensor Update Intervals, 3,400-ft Runway Separation

Section	Within-Subject Comparisons	Probability Values
4.1.1	Sensor Update Interval 1.0 s vs 2.4 s	 .309
4.1.3	Deviation Angle - 15 vs 30 deg 1.0-s sensor update interval 2.4-s sensor update interval	 .000* .000*
4.1.4	Blunder Range - near vs far range 1.0-s sensor update interval, 15-deg deviation angle 1.0-s sensor update interval, 30-deg deviation angle 2.4-s sensor update interval, 15-deg deviation angle 2.4-s sensor update interval, 30-deg deviation angle	 .001* .143 .000* .579
4.1.5	Flight Path Conditions - calm vs turbulent (30-deg deviation angle, near and far range pooled) 1.0-s sensor update interval 2.4-s sensor update interval	 .513 .715
	Flight Path Conditions - calm vs turbulent (15-deg deviation angle) 1.0-s sensor update interval, near range 1.0-s sensor update interval, far range 2.4-s sensor update interval, near range 2.4-s sensor update interval, far range	 .670 .005 .639 .242
4.1.6	Approach Blunder Type - "Single" vs "Fast/Slow" (15-deg deviation angle, calm flight path) 1.0-s sensor update interval, near range 2.4-s sensor update interval, near range 1.0-s sensor update interval, far range 2.4-s sensor update interval, far range	 .605 .201 .079 .738
	Approach Blunder Type - "Single" vs "Distraction" (Far range, calm flight path) 1.0-s sensor update interval, 15-deg deviation angle 2.4-s sensor update interval, 15-deg deviation angle 1.0-s sensor update interval, 30-deg deviation angle 2.4-s sensor update interval, 30-deg deviation angle	 .070 .003 .077 .895
4.1.6.1	"Fast/Slow Type" - 1.0-s vs 2.4-s sensor update interval (15-deg deviation, calm flight path) near range far range	 .026 .058
	Between-Subject Comparisons	
4.1.7	Controller Experience Level novice vs experienced monitor controller	 .000**

* If the probability value is .001 or less, the difference between the means is considered significant.

** If the probability value is .05 or less, the difference between the means is considered significant.

The following conclusions are made based on the analyses summarized in the above table:

(1) Sensor Update Interval – Regardless of sensor update interval, ART remained basically the same (less than 3.0 s). Under both conditions, controllers generally broke out the endangered aircraft before the blundering aircraft penetrated the NTZ. Based on application of the risk assessment model [3], the conclusion can be made that either of the sensor update intervals provides acceptable levels of safety. However, as discussed in Section 4.1.1, an advantage of the faster update interval is that it provides increased advance warning time which translates into a greater miss distance between aircraft. A second advantage, discussed in Section 4.1.8, is a lower rate of false breakouts that translates into less arrival delays.

(2) Deviation Angle — One of the most significant findings was in the area of deviation angle. In response to both sensor update intervals, controllers generally responded more quickly (approximately 1.0 s quicker) to deviations of greater angle. As discussed in Section 4.1.3, with a 30-deg blunder, penetration of the NTZ occurred more rapidly than with a 15-deg blunder. There was less time before NTZ penetration and so the controller reacted more rapidly in response to the severity of the situation.

(3) Range – Another very significant finding was in the area of range. During simulated approach blunders with 15-deg deviation angle, presented at either sensor update interval, controllers generally reacted more slowly (approximately 1.0 s slower) to approach blunders which occurred at the far vs near range. As discussed in Section 4.1.4, it appears that controllers were more tolerant of deviations at the far range since they expected deviations (and the resulting Caution Alerts) to occur due to the aircraft instability on the localizer. In response to 30-deg approach blunders, controllers reacted as quickly as possible and did not delay a decision, regardless of the range of the deviating aircraft. Again, it appears that the severity of the deviation is the driving force.

(4) Flight Path Condition – Mean ART did not differ significantly as a result of flight path condition. Based on this finding, one may conclude that when the runway separation was 3,400 ft and the PRM was used, response time remained acceptable whether calm or turbulent conditions were experienced. This conclusion is, of course, limited to the particular parameters of "turbulent condition" modeled in this simulation.

(5) Approach Blunder Type – It was found that there was no significant difference in ART in the "Single Type" vs "Fast/Slow Type" approach blunders. In this case, it does not appear that speed of the deviating aircraft was the major factor in decision-making. The major driving force in accelerating the decision to breakout an aircraft appears to have been the deviation angle.

(6) Controller Experience Level – It was found that experienced Monitor Controller responded 1.0 s slower than the controllers who did not have experience in the position. It was originally thought that experienced Monitor Controllers would be faster than the novice group. However, it appears that knowledge of the complexity of the task and the various data to consider in making a decision, caused the more experienced controller to react more slowly and with greater caution.

6.1.2 Conclusions on 4.8-s Sensor Update Interval, 3,400-ft Runway Separation

Table 6-2 provides a quick reference of the results of the comparisons performed. An asterisk indicates probability values which showed a significant difference in mean ART. Reference is made to the section in which the analysis is discussed in detail.

Table 6-2

Comparisons Performed In Study I

4.8-s Sensor Update Interval, 3,400-ft Runway Separation

Section	Within-Subject Comparisons	Probability Values
4.2.1	Sensor Update Interval	
	4.8-s vs 1.0-s sensor update interval	.001*
	4.8-s vs 2.4-s sensor update interval	.005
4.2.2	Deviation Angle	
	15 deg vs 30 deg	.508

* If the probability value is .001 or less, the difference between the means is considered significant.

As indicated in Table 6-2 the variable in which mean ART was found to differ significantly was sensor update interval. The stringent criteria set through application of the Bonferroni Adjustment was met in the case of 4.8-s vs 1.0-s sensor update interval. In the case of 4.8-s vs 2.4-s sensor update interval, a strong trend towards significance was demonstrated. Controller ART was significantly slower (by approximately 1.0 s) when the 4.8-s sensor update interval was used vs the other two faster update intervals. Whether the deviation angle was 15 deg or 30 deg the ART remained at approximately 4.0 s. As discussed in Section 4.2.1, based on preliminary findings presented to the Working Group, the group considered this sensor update interval to be too slow for the operation to be safely conducted with 3,400-ft runway separation. Subsequent testing was therefore conducted to explore the case of 4.8-s sensor update interval and 4,300-ft runway separation.

6.1.3 Conclusions on 4.8-s Sensor Update Interval, 3,400-ft vs 4,300-ft Runway Separation

This section includes the conclusions reached from the results obtained from the simulations of approach blunders presented at 4.8-s sensor update interval, 3,400-ft vs 4,300-ft runway separation. The 4,300-ft separation case was tested to gain some understanding of conducting the simultaneous independent approaches at today's standard runway separation of a minimum of 4,300 ft. In this testing configuration the controllers had the advantage of the PRM high-resolution, color display with automatic alerting and the advantage of greater radar accuracy as compared to the current system in use.

Controller ART was significantly faster when the runway separation was increased from 3,400 ft to 4,300 ft (4.2 s at 3,400-ft separation vs 1.6 s at 4,300-ft separation). The results were highly significant. As discussed in Section 4.3, one possible explanation for the extreme difference

in mean ART concerns the presence of a larger normal operating zone (NOZ) in the 4,300-ft runway separation condition. The controllers had the opportunity to observe the blundering aircraft for one or two more radar intervals prior to NTZ penetration. When the Caution Alert sounded, the aircraft was far from the centerline. There was little likelihood that this was a deviation caused by TNSE and therefore the controller was confident in making the breakout-decision and responded quickly.

The occurrence of these rapid response times appears to indicate that the operation could be successfully performed at this separation when the PRM is used. This conclusion was confirmed by the application of the risk assessment model [5]. The PRM blunder resolution performance was tested at a 4,300-ft runway separation for the "least favorable" condition: a 4.8-s sensor update interval, 30-deg blunders, far range. The percent of trials with miss distances under 500 ft was 0.32% at 1-milliradian accuracy and 0.310% at 2-milliradian accuracy. The 4,300-ft/4.8-s probability of 0.32% is very similar to the results on 3,400-ft/1.0-s sensor update interval and 3,400-ft/2.4-s sensor update interval [5].

6.1.4 Additional Conclusions on 4,300-ft Runway Separation

Regarding the simulations showing 4,300-ft separation, Table 6-3 provides a quick reference of the results of the comparisons performed in Section 4.3. An asterisk indicates probability values which showed a significant difference in mean ART. Reference is made to the section in which the analysis is discussed in detail.

Table 6-3

Comparisons Performed In Study I

4.8-s Sensor Update Interval, 4,300-ft Runway Separation

Section	Within-Subject Comparisons	Probability Values
4.4.1	Deviation Angle 15 deg vs 30 deg	.121
4.4.2	Approach Blunder Range - near vs far range 30-deg deviation angle, calm flight path	.000*
4.4.3	Flight Path Conditions - calm vs turbulent 15-deg deviation angle, near range, calm flight path	.895
4.4.4	Approach Blunder Type - "Single" vs "Fast/Slow" 15-deg deviation angle, near range, calm flight path	.875

* If the probability value is .001 or less, the difference between the means is considered significant.

As indicated in Table 6-3, the variable in which ART was found to differ significantly was blunder range. As discussed in Section 4.4.2, ART in response to approach blunders at far range tends to be longer since TNSE is greater at far vs near range and the controllers seemed to wait for the aircraft to stabilize on the localizer before making a breakout decision.

6.2 STUDY II

Table 6-4 provides a quick reference of the results of the comparisons performed in Section 5. An asterisk indicates probability values which showed a significant difference in mean ART. Reference is made to the section in which the analysis is discussed in detail.

Table 6-4

Comparisons Performed In Study II

1.0-s and 2.4-s Sensor Update Interval, 3,000-ft Runway Separation

Section	Within-Subject Comparisons	Probability Values
5.2	Deviation angle - 15 vs 30 deg	
	1.0-s sensor update interval	.828
	2.4-s sensor update interval	.044
5.3	Blunder Range - Near vs Far Range	
	1.0-s sensor update interval, 15-deg deviation angle	.002*
	1.0-s sensor update interval, 30-deg deviation angle	.056
	2.4-s sensor update interval, 15-deg deviation angle	.002*
	2.4-s sensor update interval, 30-deg deviation angle	.905
5.4	Approach Blunder Type - "Single" vs "Fast/Slow"	
	(15-deg deviation angle)	.029
	1.0-s sensor update interval, near range	.355
	2.4-s sensor update interval, near range	.927
	1.0-s sensor update interval, far range	.118
	2.4-s sensor update interval, far range	

* If the probability value is .005 or less, the difference between the means is considered significant.

Findings regarding the effect of sensor update interval (1.0 s vs 2.4 s) were similar to those of Study I. Overall, ART did not differ significantly on the basis of sensor update interval. Regarding blunder range, in response to approach blunders with a 15-deg deviation angle, controllers tended to respond more slowly to blunders occurring at the far range. As in Study I, controllers were probably waiting for the aircraft at the far range to stabilize on the localizer before making a breakout decision.

A major concern which surfaced in Study II was the effect of TNSE due to the closeness of the runways in the 3,000-ft separation condition. The effect of TNSE seems to have caused controllers to question the safety of this operation, regardless of the speed of their ART. The main result of Study II was the realization of the need for consideration of means to lessen the effect of TNSE, thus decreasing the frequency and magnitude of deviations and NTZ penetrations. These means should be applied through simulation study, before a decision can be made regarding safety.

6.3 CONTROLLER OPINION – STUDY I AND II

Controllers were very enthusiastic about the PRM. They stated that through use of this equipment, the standard runway spacing could be reduced to the 3,400-ft spacing demonstrated. Controllers unanimously agreed that the PRM was superior to the Automated Radar Terminal System (ARTS). They especially liked the high-resolution color display and automated alerts. All, but two controllers agreed that approaches could be safely conducted at 3,400-ft spacing, if monitored by the PRM. The two controllers wished to reserve their opinion until they had more familiarity with the system.

Regarding 3,000-ft spacing, all controllers were not of the opinion that the operation could be safely conducted with PRM. Five of the ten controllers thought that operations can be safely conducted with 1.0-s sensor update interval. They were not sure about the safety of use of 2.4-s sensor update interval. As discussed above, it appears that controllers were hesitant due to the effect of TNSE which occurs at the lesser runway spacing of 3,000 ft. Controllers recommended that means be explored to reduce the effect of TNSE or else it would be necessary to limit the controller's time on position. It was believed that, due to the high number of non-blunder alerts, controllers would become fatigued at this position within approximately 30 to 60 minutes.

6.4 RECOMMENDATIONS

With the benefit of 20/20 hindsight, there are elements of the experiment that we would do differently, given the opportunity to conduct further experimentation. In order to enhance the realism of the simulation, the noise level representative of an actual TRACON would be included during the simulations. In addition, changes would be made in the pre-recorded audio of the dialog between controller and pilots. In the pre-recorded audio which accompanied each visual presentation of an arrival push, one controller and one pilot were used. For future studies, a voice synthesizer is recommended so that the pre-recorded audio will sound like various pilots and will therefore be more realistic.

Further study needs to be performed regarding 3,000-ft spacing. Ways to alleviate the effect of TNSE need to be explored.

One such study has recently been conducted at the FAA Technical Center, through the collaborative efforts of The Multiple Parallel Technical Work Group, the FAA Technical Center, and CTA Incorporated. The study examined dual parallel runways spaced 3,000 ft apart with one ILS approach localizer offset by 1 deg. Having one runway with a 1-deg localizer offset increases the NOZ for each runway. With the increased NOZ, there is a reduction in the effect of TNSE and, therefore, a reduction in the number of NTZ entries and accompanying nuisance alerts. A report of findings is expected in the near future.

In our studies the look-ahead time for the Caution Alert was 10 s. The effect of various look-ahead times should be explored in scenarios depicting runway separations of interest. We need to explore the trade-off of having more notice vs the possibility of increasing the number of false alerts and subsequent false breakouts.

We should also take another look at the predictor line. Controllers were concerned at how erratic it appeared when the sensor update interval was as fast as 1.0 s. Although we would like to see a smoother movement for the predictor line, i.e., less erratic jumping and greater consistency of position, we do not want to have substantial losses in the accuracy of prediction.

APPENDIX A

Arrival Pushes Shown In Study I, Weeks 1 through 12

Arrival Push	Blunder Number and Type	Update Interval (sec)	Runway Separation (ft)	Angle (deg)	Range (nmi)	Flt. Path Conditions
1A and 1B	11. Distraction	1.0	3,400	15	far	Calm
	5. Single	1.0	3,400	30	near	Calm
	13. Simult/Miss	1.0	3,400	15	0.5	Calm
	12. Distraction	1.0	3,400	30	far	Calm
	7. Single	1.0	3,400	30	far	Calm
2A and 2B	10. Fast/Slow	1.0	3,400	15	far	Calm
	3. Single	1.0	3,400	15	far	Calm
	1. Single	1.0	3,400	15	near	Calm
	9. Fast/Slow	1.0	3,400	15	near	Calm
3A and 3B	8. Single	1.0	3,400	30	far	Turbulent
	4. Single	1.0	3,400	15	far	Turbulent
	6. Single	1.0	3,400	30	near	Turbulent
	2. Single	1.0	3,400	15	near	Turbulent
4A and 4B	3. Single	2.4	3,400	15	far	Calm
	5. Single	2.4	3,400	30	near	Calm
	10. Fast/Slow	2.4	3,400	15	far	Calm
	12. Distraction	2.4	3,400	30	far	Calm
	9. Fast/Slow	2.4	3,400	15	near	Calm
5A and 5B	1. Single	2.4	3,400	15	near	Calm
	13. Simult/Miss	2.4	3,400	15	0.5	Calm
	7. Single	2.4	3,400	30	far	Calm
	11. Distraction	2.4	3,400	15	far	Calm
6A and 6B	6. Single	2.4	3,400	30	near	Turbulent
	4. Single	2.4	3,400	15	far	Turbulent
	8. Single	2.4	3,400	30	far	Turbulent
	2. Single	2.4	3,400	15	near	Turbulent
7A and 7B	5. Single	4.8	3,400	30	far	Calm
	8. Fast/Slow	4.8	3,400	15	far	Calm
	1. Single	4.8	3,400	15	near	Calm
	9. Distraction	4.8	3,400	15	far	Calm
8A and 8B	3. Single	4.8	3,400	30	near	Calm
	10. Distraction	4.8	3,400	30	far	Calm
	11. Simult/Miss	4.8	3,400	15	0.5	Calm
	7. Fast/Slow	4.8	3,400	15	near	Calm
9A and 9B	4. Single	4.8	3,400	30	near	Turbulent
	6. Single	4.8	3,400	30	far	Turbulent
	2. Single	4.8	3,400	15	near	Turbulent

APPENDIX B

Arrival Pushes Shown in Study I, Weeks 13 through 25

Note: The only difference between the arrival pushes presented in Weeks 1-12 and Weeks 13-25 is the change in runway separation in the 4.8-s sensor update interval scenarios. They were changed from 3,400 ft in Weeks 1-12 to 4,300 ft in Weeks 13-25.

Arrival Push	Blunder Number and Type	Update Interval (sec)	Runway Separation (ft)	Angle (deg)	Range (nmi)	Flt. Path Conditions
1A and 1B	11. Distraction	1.0	3,400	15	far	Calm
	5. Single	1.0	3,400	30	near	Calm
	13. Simult/Miss	1.0	3,400	15	0.5	Calm
	12. Distraction	1.0	3,400	30	far	Calm
	7. Single	1.0	3,400	30	far	Calm
2A and 2B	10. Fast/Slow	1.0	3,400	15	far	Calm
	3. Single	1.0	3,400	15	far	Calm
	1. Single	1.0	3,400	15	near	Calm
	9. Fast/Slow	1.0	3,400	15	near	Calm
3A and 3B	8. Single	1.0	3,400	30	far	Turbulent
	4. Single	1.0	3,400	15	far	Turbulent
	6. Single	1.0	3,400	30	near	Turbulent
	2. Single	1.0	3,400	15	near	Turbulent
4A and 4B	3. Single	2.4	3,400	15	far	Calm
	5. Single	2.4	3,400	30	near	Calm
	10. Fast/Slow	2.4	3,400	15	far	Calm
	12. Distraction	2.4	3,400	30	far	Calm
	9. Fast/Slow	2.4	3,400	15	near	Calm
5A and 5B	1. Single	2.4	3,400	15	near	Calm
	13. Simult/Miss	2.4	3,400	15	0.5	Calm
	7. Single	2.4	3,400	30	far	Calm
	11. Distraction	2.4	3,400	15	far	Calm
6A and 6B	6. Single	2.4	3,400	30	near	Turbulent
	4. Single	2.4	3,400	15	far	Turbulent
	8. Single	2.4	3,400	30	far	Turbulent
	2. Single	2.4	3,400	15	near	Turbulent
7A and 7B	5. Single	4.8	4,300	30	far	Calm
	8. Fast/Slow	4.8	4,300	15	far	Calm
	1. Single	4.8	4,300	15	near	Calm
	9. Distraction	4.8	4,300	15	far	Calm
8A and 8B	3. Single	4.8	4,300	30	near	Calm
	10. Distraction	4.8	4,300	30	far	Calm
	11. Simult/Miss	4.8	4,300	15	0.5	Calm
	7. Fast/Slow	4.8	4,300	15	near	Calm
9A and 9B	4. Single	4.8	4,300	30	near	Turbulent
	6. Single	4.8	4,300	30	far	Turbulent
	2. Single	4.8	4,300	15	near	Turbulent

APPENDIX C

Controller Pair	Counterbalanced Order of Arrival Push Presentations								
1	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B	7/ 7	8A 8B	9A 9B
2	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B
3	3A 3B	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B
4	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B
5	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B
6	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B
7	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B
8	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B	7A 7B
9	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B
10	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B
11	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B
12	3A 3B	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B
13	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B
14	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B
15	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B
16	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B
17	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B	7A 7B
18	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B
19	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B	9BA 9
20	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B
21	3A 3B	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B
22	4A 4B	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B
23	5A 5B	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B
24	6A 6B	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B
25	7A 7B	8A 8B	9A 9B	1A 1B	2A 2B	3A 3B	4A 4B	5A 5B	6A 6B

APPENDIX D

Arrival Pushes Shown in Study II

Note: Study II used a subset of the same arrival pushes used in Study I. All of the arrival pushes were presented at either 1.0- or 2.4-s sensor update interval. The difference between the arrival pushes used in Study I and Study II is that the runway separation in Study II was depicted as 3,000 ft rather than the previously depicted 3,400 ft. No 4.8-s sensor update interval approach blunders were used. Only calm flight path conditions were used. In addition, the distraction scenarios were changed to be single blunders without distractions.

Arrival Push	Blunder Number and Type	Update Interval (sec)	Runway Separation (ft)	Angle (deg)	Range (nmi)	Flt. Path Conditions
1A and 1B	1. Single	1.0	3,000	15	far	Calm
	2. Single	1.0	3,000	30	near	Calm
	3. Simult/Miss	1.0	3,000	15	0.5	Calm
	4. Single	1.0	3,000	30	far	Calm
	5. Single	1.0	3,000	30	far	Calm
2A and 2B	6. Fast/Slow	1.0	3,000	15	far	Calm
	7. Single	1.0	3,000	15	far	Calm
	8. Single	1.0	3,000	15	near	Calm
	9. Fast/Slow	1.0	3,000	15	near	Calm
4A and 4B	14. Single	2.4	3,000	15	far	Calm
	15. Single	2.4	3,000	30	near	Calm
	16. Fast/Slow	2.4	3,000	15	far	Calm
	17. Single	2.4	3,000	30	far	Calm
	18. Fast/Slow	2.4	3,000	15	near	Calm
5A and 5B	19. Single	2.4	3,000	15	near	Calm
	20. Simult/Miss	2.4	3,000	15	0.5	Calm
	21. Single	2.4	3,000	30	far	Calm
	22. Distraction	2.4	3,000	15	far	Calm

APPENDIX E

Airline and Aircraft Types Included in the Simulation

Airline	Percent of Flights
NWA	43
DAL	14
NWX	18
FDX	12
USA	6
General Aviation	6
UAL	1

Aircraft	Percent of Flights
B727	31
DC9	20
B757	15
BA31	9
SF34	8
B737	7
LR25	2
DC10	2
AC21	2
B767	2
BEnn	0.6
LR55	0.6
C172	0.2
PA30	0.2
C14	0.2
DH4	0.2

APPENDIX F

PRECISION RUNWAY MONITOR

CONTROLLER OPINION SURVEY

FOR

MEMPHIS AND RALEIGH-DURHAM STUDIES

Subject ID: ________
Interviewer ID: ________
Date: ________

1. **PROFESSIONAL EXPERIENCE:** (to the nearest half-year)

1.1 Radar Control Experience ________ Years
1.2 Parallel Runway Monitor Experience ________ Years
1.3 Parallel Runway Monitor E-system Exposure ☐ Yes ☐ No (RDU ONLY)

---

2. **GENERAL ACCEPTANCE:**

<u>Comments</u>:

2.1	PRM enabled me to monitor the final approach better than the existing ARTS system.	Agree __ Disagree __ Undecided __
2.2	PRM's high resolution color monitor is better for the monitor function than the current ARTS system display.	Agree __ Disagree __ Undecided __
2.3	The PRM display with the automated alarms made it easier to detect and resolve potential and actual blunders/deviations better than the existing ARTS system.	Agree __ Disagree __ Undecided __
2.4	Independent IFR approaches to runways separated by 3,400/3,500 ft can be safely conducted using the PRM.	Agree ___ Disagree ___ Undecided ___

3. **MONITOR CONTROLLER FUNCTIONS**

<u>Comments</u>:

3.1	PRM is useful as a final approach monitor to prevent penetration of the NTZ.	Agree __ Disagree __ Undecided __
3.2	PRM is useful in resolving approach blunders once they have occurred.	Agree __ Disagree __ Undecided __

3.3	PRM is useful in detecting deviations from the designated approach course.	Agree __ Disagree __ Undecided __	
3.4	PRM is useful in monitoring simultaneous missed approach to ensure that the required divergence is achieved.	Agree __ Disagree __ Undecided __	

4. NTZ ALERTS

			Comments:
4.1	The Caution Visual Alert (Yellow), predicting x seconds or less until NTZ penetration, is useful.	Agree __ Disagree __ Undecided __	
4.2	The Voice Alert accompanying the Caution Visual Alert (Yellow) is useful.	Agree __ Disagree __ Undecided __	
4.3	The Warning Visual Alert (Red), indicating that NTZ penetration has occurred, is useful.	Agree __ Disagree __ Undecided __	

5. DISPLAY INFORMATION CONTENT AND PRESENTATION

			Comments:
5.1	The information presented in the PRM display is well-placed and easily visible.	Agree __ Disagree __ Undecided __	
5.2	The written information presented in the PRM display is easily read.	Agree __ Disagree __ Undecided __	
5.3	The color display is more effective than a monochrome display.	Agree __ Disagree ___ Undecided ___	
5.4	The ability to rotate the runways from the actual runway orientation to either the vertical or horizontal is a sufficient rotational capability (RDU ONLY).	Agree ___ Disagree ___ Undecided ___	
5.5	The parallel 200-ft lines are a useful aid in detecting deviations from the approach course, and in predicting the potential for an NTZ penetration.	Agree ___ Disagree ___ Undecided ___	
5.6	The color selection for the features on the display is suitable.	Agree ___ Disagree___ Undecided ___	

6. Instructions: Listed below are all the information items automatically provided or available by selection. Indicate whether you agree, disagree, or are undecided that the item is useful in assisting you to perform the Monitor Controller task. List any changes you would like to see made in the information included (Content) or the way in which it appears (Presentation).

	Item	Content	Presentation	Useful	Comments
6.1	History Trail	Any aircraft with more than one position report will display as many of them as requested.	Green Dashes	Agree __ Disagree__ Undecided __	
6.2	Projected Position Vector	For all aircraft that have at least two good position reports, a trend vector is drawn from the aircraft symbol out to the point where it would be, if the aircraft continued at its current velocity,in the number of seconds you have selected.	Cyan Straight line	Agree __ Disagree __ Undecided __	
6.3	200-ft deviation lines	Indicate 200-ft Increments toward NTZ	White lines	Agree __ Disagree __ Undecided __	

7. **TRAINING**

Comments:

7.1 Adequate training time was provided to become familiar with the display before beginning the Testing.

Agree __
Disagree __
Undecided __

7.2 All information needed, to aid me in performing the monitoring task, was provided.

Agree __
Disagree __
Undecided __

(Please comment on anything omitted from the training that would have helped you to better perform the monitoring task.)

8. THE SIMULATION

			Comments
8.1	The simulated traffic density was realistic.	Agree __ Disagree __ Undecided __	
8.2	The simulated aircraft "blunder" trajectories were realistic.	Agree __ Disagree __ Undecided __	
8.3	The simulated aircraft missed approach trajectories were realistic.	Agree __ Disagree __ Undecided __	
8.4	The audio portion of the simulation was realistic.	Agree __ Disagree __ Undecided __	
8.5	Please comment on any changes to the simulation which you feel would enhance its realism.		
8.6	Were there any factors of the simulation which may have affected the quality of the reaction time measurement?		

9. ADDITIONAL COMMENTS:

APPENDIX G

PRECISION RUNWAY MONITOR

CONTROLLER OPINION SURVEY

FOR

MEMPHIS STUDY II

Subject ID: ________
Interviewer ID: ________
Date: ________

1. **PROFESSIONAL EXPERIENCE:** (to the nearest half-year)

1.1 Radar Control Experience ________ Years
1.2 Parallel Runway Monitor Experience ________ Years

---

2. **GENERAL ACCEPTANCE:**

Comments:

2.1 Independent IFR approaches to runways separated by 3,000 ft can be safely conducted using the PRM.

Agree ___
Disagree ___
Undecided ___

3. **TRAINING**

Comments:

3.1 Adequate training time was provided to become familiar with the display before beginning the Testing.

Agree __
Disagree __
Undecided __

3.2 All information needed, to aid me in performing the monitoring task, was provided.

Agree __
Disagree __
Undecided __

(Please comment on anything omitted from the training that would have helped you to better perform the monitoring task.)

4. **THE SIMULATION**

Comments

4.1 The simulated traffic density was realistic.

Agree __
Disagree __
Undecided __

4.2 The simulated aircraft "blunder" trajectories were realistic.

Agree __
Disagree __
Undecided __

4.3 The simulated aircraft missed approach trajectories were realistic.

Agree __
Disagree __
Undecided __

4.4 The audio portion of the simulation was realistic.

Agree __
Disagree __
Undecided __

4.5 Please comment on any changes to the simulation which you feel would enhance its realism.

4.6 Were there any factors of the simulation which may have affected the quality of the reaction time measurement?

5. **ADDITIONAL COMMENTS:**

APPENDIX H

The Blunder Table
Examples of Database Queries and Replies

The following is a listing of some SQL (Structure Query Language) queries and replies. After logging onto the controller response database, these queries may be executed to obtain information rrom the on-line ORACLE data dictionary concerning the structure of the BLUNDER table.

Query Example #1: This query returns a one sentence description of the BLUNDER table.

```
SQL > SELECT COMMENTS
   2  FROM SYS.ALL_TAB_COMMENTS
   3  WHERE TABLE_NAME = 'BLUNDER'
   4  AND OWNER = 'ZEUS';
```

Reply:

BLUNDER: This table contains the parameters of each scripted blunder used in the controller response study.

Query Example #2: This query returns the names of the columns (blunder parameters) in the BLUNDER table, whether the column must contain data for each row (NOT NULL), and the data type of each column. NUMBER(38) is the ORACLE format for an integer. NUMBER(2,1) is the ORACLE format for a two digit number with one digits to the right of the decimal point. CHAR(8) is the ORACLE format for a character array containing at most eight characters.

```
SQL > DESC BLUNDER;
```

Reply:

Name	Null?	Type
SCENARIO	NOT NULL	CHAR(8)
MAP		CHAR(8)
BLUNDER	NOT NULL	CHAR(4)
TYPE	NOT NULL	CHAR(24)
ANGLE	NOT NULL	NUMBER(38)
RANGE	NOT NULL	NUMBER(38)
PERIOD	NOT NULL	NUMBER(2,1)
WEATHER	NOT NULL	CHAR(16)
SEAT	NOT NULL	CHAR(8)

Query Example #3: This query returns a more detailed description of the ranges and representative values of each column in the BLUNDER table.

```
SQL > SELECT COMMENTS
   2  FROM SYS.ALL_COL_COMMENTS
   3  WHERE TABLE_NAME = 'BLUNDER'
   4  AND OWNER = 'ZEUS';
```

Reply:

SCENARIO: The simulated blunder scenario tape identifier; e.g., VII, IX-A.
MAP: The PRM display map selected on the monitor, NORTH or SOUTH.
BLUNDER: The unique blunder identifier from 1 to 37.
TYPE: The type of blunder; e.g., SINGLE, DISTRACTION, FAST/SLOW, SIMULTANEOUS/MISS.
ANGLE: The blunder angle in degrees from the ILS, 15 or 30.
RANGE: The distance from the threshold of the blunder (nmi); e.g., 0.5, 2, 3, 4, 8, 9,10, 11, 12.
PERIOD: The display update period in seconds; e.g., 0.5, 1.0, 2.4, 4.8.
WEATHER: The weather conditions during a parallel approach; e.g. CALM, TURBULENT.
SEAT: The controller monitor seat; e.g., LEFT, RIGHT.

APPENDIX I

Controller Response Table
Examples of Database Queries and Replies

The following is a listing of some SQL (Structure Query Language) queries and replies. After logging onto the controller response database, these queries may be executed to obtain information from the on-line ORACLE data dictionary concerning the structure of the CONTROLLER_RESPONSE table.

Query Example #1: This query returns a one sentence description of the CONTROLLER_RESPONSE table.

```
SQL > SELECT COMMENTS
  2   FROM SYS.ALL_TAB_COMMENTS
  3   WHERE TABLE_NAME = 'CONTROLLER_RESPONSE'
  4   AND OWNER = 'ZEUS';
```

Reply:

CAUTION_ALERT: This table contains the times from onset of the yellow alert to controller response.

Query Example #2: This query returns the names of the columns in the CONTROLLER_RESPONSE table, whether the column must contain data for each row (NOT NULL), and the data type of each column. NUMBER(38) is the ORACLE format for an integer. NUMBER(4,2) is the ORACLE format for a four digit number with two of the four digits to the right of the decimal point. CHAR(4) is the ORACLE format for character array of at most four characters.

```
SQL > DESC CONTROLLER_RESPONSE;
```

Reply:

Name	Null?	Type
WEEK		NUMBER(38)
BLUNDER	NOT NULL	CHAR(4)
AIRPORT	NOT NULL	CHAR(4)
CONTROLLER	NOT NULL	CHAR(8)
RESPTIME		NUMBER(4,2)
SEAT	NOT NULL	CHAR(8)
STAMP	NOT NULL	CHAR(24)

Query Example #3: This query returns a more detailed description of the ranges and representative values for each column in the CONTROLLER_RESPONSE table.

```
SQL > SELECT COMMENTS
  2   FROM SYS.ALL_COL_COMMENTS
  3   WHERE TABLE_NAME = 'CONTROLLER_RESPONSE'
  4   AND OWNER = 'ZEUS';
```

Reply:

WEEK: The number of the week of the study for this measurement, 1 through 25.
BLUNDER: The unique blunder identifier from 1 to 29, 30L, 30R, 31L, 31R and 32 to 37.
AIRPORT: The three letter airport designation; MEM, THB, LXR.
CONTROLLER: The test subject (controller) identifier; e.g., M3-B, G12-A.
RESPTIME: The controller response time, in seconds, to the warning of a blunder.
SEAT: The controller monitor seat; e.g., LEFT, RIGHT.
STAMP: A quality control stamp or description of the measurement.

APPENDIX J

The Caution Alert Table
Examples of Database Queries and Replies

The following is a listing of some SQL (Structure Query Language) queries and replies. After logging onto the controller response database, these queries may be executed to obtain information from the on-line ORACLE data dictionary concerning the structure of the BLUNDER table.

Query Example #1: This query returns a one sentence description of the CAUTION_ALERT table.

```
SQL > SELECT COMMENTS
    2  FROM SYS.ALL_TAB_COMMENTS
    3  WHERE TABLE_NAME = 'CAUTION_ALERT'
    4  AND OWNER = 'ZEUS';
```

Reply:

CAUTION_ALERT: This table contains the caution alert lead times for each blunder from the controller study.

Query Example #2: This query returns the names of the columns in the CAUTION_ALERT table, whether the column must contain data for each row (NOT NULL), and the data type of each column. NUMBER(38) is the ORACLE format for an integer. NUMBER(4,2) is the ORACLE format for a four digit number with two of the four digits to the right of the decimal point. CHAR(8) is the ORACLE format for a character array containing at most eight characters.

```
SQL > DESC CAUTION_ALERT;
```

Reply:

Name	Null?	Type
SCENARIO	NOT NULL	CHAR(8)
BLUNDER	NOT NULL	CHAR(4)
AIRPORT	NOT NULL	CHAR(4)
CONTROLLER	NOT NULL	CHAR(8)
LEADTIME		NUMBER(4,2)
SEAT	NOT NULL	CHAR(48)

Query Example #3: This query returns a more detailed description of the ranges and representative values of each column in the BLUNDER table.

```
SQL > SELECT COMMENTS
    2  FROM SYS.ALL_COL_COMMENTS
    3  WHERE TABLE_NAME = 'CAUTION_ALERT'
    4  AND OWNER = 'ZEUS';
```

Reply:

SCENARIO: The simulated blunder scenario tape identifier; e.g. ,VII, IX-A.
BLUNDER: The unique blunder identifier from 1 to 29, 30L, 30R, 31L, 31R and 32 to 37.
AIRPORT: The three letter airport designation; MEM, THB, LXR.
CONTROLLER: The test subject (controller) identifier; e.g., M3-B, G12-A.
LEADTIME: The data cluster average of the measured caution alert lead time (sec).
STAMP: A quality control stamp or description of the measurement.

APPENDIX K

Adjusted Probability Criteria for Within-Subject Comparisons Performed in Study I and II

Study I - Section	Analysis Area	Number of Planned Within-Subject Comparisons	Probability Criteria (Bonferroni Adjusted)
4.1.1 thru 4.1.6	1.0-s and 2.4-s sensor update interval, 3,400-ft runway separation	23	
4.2.1 and 4.2.2	4.8-s sensor update interval, 3,400-ft runway separation	3	
4.4.1 thru 4.4.4	4.8-s sensor update interval, 4,300-ft runway separation	4 Total: 30	.001 or less

Study II - Section	Analysis Area	Number of Planned Within-Subject Comparisons	Probability Criteria (Bonferroni Adjusted)
5.2 thru 5.4	1.0-s and 2.4-s sensor update interval, 3,000-ft runway separation	10	.005 or less

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